Total Maximum Daily Loads of DO and Pathogens for Gargathy Creek (-Upper, -Lower, and Riverine Portions) in Accomack County, Virginia

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List of Abbreviations

ASAE	American Society of Agricultural Engineers
BOD	Biochemical Oxygen Demand
BMP	Best Management Plan
CFR	Code of Federal Regulations
COD	Chemical Oxygen Demand
CWA	Clean Water Act
DIN	Dissolved Inorganic Nitrogen
DO	Dissolved Oxygen
EFDC	Environmental Fluid Dynamics Computer Code
EPA	Environmental Protection Agency
FA	Future Allocation
GIS	Geographic Information System
LA	Load Allocation
LSPC	Loading Simulation Program C^{++}
MOS	Margin of Safety
MOU	Memorandum of Understanding
MS4s	Municipal Separate Storm Sewer Systems
NLCD	National Land Cover Data
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
OC	Organic Carbon
SOD	Sediment Oxygen Demand
SWCB	State Water Control Board
TIN	Total Inorganic Nitrogen
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus
USDA	United States Department of Agriculture
USGS	United States Geological Survey
UTGC	Unnamed Tributary to Gargathy Creek
VA-DCR	Virginia Department of Conservation and Recreation
VA-DEQ	Virginia Department of Environmental Quality
VADGIF	Virginia Department of Game and Inland Fisheries
VDH	Virginia Department of Health
VPDES	Virginia Pollutant Discharge Elimination System
WLA	Wasteload Allocation
WQAIR	Water Quality Assessment Integrated Report

WQC	Water Quality Criteria
WQLS	Water Quality Limited Segments
WQMIRA	Water Quality Monitoring, Information, and Restoration Act
WQMP	Water Quality Management Plans
WQS	Water Quality Standard
WWTP	Waste Water Treatment Plant

EXECUTIVE SUMMARY

Introduction

Section 303(d) of the Clean Water Act (CWA) and the United States Environmental Protection Agency's (USEPA's) Water Quality Planning and Management Regulations (40 CFR Part 130) requires states to develop total maximum daily loads (TMDLs) for waterbodies that are exceeding water quality standards (WQSs). TMDLs represent the total pollutant loading that a waterbody can receive without violating WQSs. The TMDL process establishes the allowable loadings of pollutants for a waterbody based on the relationship between pollution sources and in-stream water quality conditions. By following the TMDL process, states can establish controls based on water quality conditions to reduce pollution from both point and nonpoint sources to restore and maintain the quality of their water resources.

Gargathy Creek is located in Accomack County, Virginia, along the Eastern Shore of the Delmarva Peninsula. The Creek drains east to the Atlantic Ocean through Gargathy Inlet. Gargathy Creek-Upper (VAT-D03E_GAR01A04), Gargathy Creek - Lower (VAT-D03E_GAR02A04) were listed on the 2006 and 2010 Virginia 305(b)/303(d) Water Quality Assessment Integrated Report (VA-DEQ, 2006; 2010) as having failed to support their aquatic life designated use due to violations of Virginia's Dissolved Oxygen (DO) criteria. The freshwater portion of the Gargathy Creek (VAT-D03R_GAR01A02) is listed as an impaired waterbody due to violation of the State's water quality standard for *Escherichia coli*. Based on the water quality assessment, it does not support its designated use of aquatic life and primary contact recreation (e.g., swimming and fishing). TMDLs have been developed to meet both DO and *Escherichia coli* standards. This document, upon approval of EPA, establishes a TMDL of DO for Gargathy Creek-Upper and -Lower, and a pathogen (*E. coli*) TMDL for freshwater portion of the Gargathy Creek.

Assessment Unit	Water name	Location Description	Cause Category	Cause Name	Size (sq. miles)
VAT-D03E_GAR01A04	Gargathy Creek – Upper	Upper estuarine portion of Gargathy Creek from headwaters downstream to end of DSS condemnation.	5A	Oxygen, dissolved	0.12
VAT-D03E_GAR02A04	Gargathy Creek – Lower	Lower estuarine portion of Gargathy Creek, from point at Cutoff Creek to downstream confluence with Gargathy Bay (RM 1.38).	5A	Oxygen, dissolved	0.01
VAT-D03E_GAR01A02	Gargathy Creek	Riverine portion of Gargathy Creek, from headwaters downstream to beginning of tidal waters. Located southeast of Nelsonia.	5A	Escherichia coli	2.69

Sources of Pathogens (E. coli) and Nutrients

The watershed approach was applied to conduct source assessment. There is no point source such as a wastewater treatment plant (WWTP) in the Gargathy Creek watershed. The potential sources of pathogens in the watershed are nonpoint sources, including livestock, wildlife, land application of biosolids, pets, failing septic systems, and uncontrolled discharges (straight pipes conveying gray water from kitchen and laundry areas of private homes, etc.). The excessive nutrient sources are mainly due to nonpoint sources through both surface and subsurface inflows, including fertilizer, manure application, livestock, wildlife, and failing septic systems.

Modeling Approach

A system of numerical models was applied to simulate the loadings of organic matter and nutrients, as well as pathogens (*E. coli*) from the Gargathy Creek watershed, and the resulting response of in-stream water quality variables. The watershed model, Loading Simulation Program in C^{++} (LSPC), developed by the USEPA, was selected to simulate the watershed hydrology, nutrient loads, and pathogen load to Gargathy Creek. The Environmental Fluid Dynamics Computer Code (EFDC) was used to simulate the eutrophication processes and transport of nutrients, and *E. coli* in the receiving water. The water column processes were coupled to the sediment diagenesis, which simulates the mineralization of particulate organic matters deposited from the overlying water column and the resulting fluxes of inorganic substances, and the sediment oxygen demand (SOD) back to the water column.

Endpoint

The numerical criteria for DO for Gargathy Creek –Upper and -Lower are a minimum of 4.0 mg/l and a daily average of 5.0 mg/l. The numerical criteria for *E. coli* is a *monthly geometric mean* of 126 CFU/100mL and a Single Sample Maximum of 235 CFU/100 ml. The endpoints were established based on the aquatic life and designated use of primary contact recreation (e.g., swimming and fishing).

Load Allocation Scenarios

For the aquatic life use impairment, the endpoint is a minimum of 4.0 mg/l and a daily average of 5.0 mg/l. For the recreation use impairment, the appropriate water quality standards were determined to be a monthly geometric mean value of 126 CFU/100 ml and a Single Sample Maximum of 235 CFU/100mL for *E. coli.* Calibrated model simulation results were used to establish the existing loads in the system. The loads that are necessary to meet water quality standards were established for the TMDLs. The difference between the TMDL and the existing loading (annual base loading) represents the necessary level of reduction. The maximum reduction required to meet the DO water quality standard is approximately 34% for total nitrogen. The maximum reduction required to meet the *E. coli* water quality standard is approximately 60%. TMDLs for nitrogen and enterococci are summarized below:

	TMDL	=	LA	+	WLA	+	FA	+	MOS (5%)
Total Nitrogen (lb/day)	95.1		90.4		n/a		n/a		4.7
E. coli (counts)	1.80×10^{10}		1.69×10^{10}				1.8×10^{8}		9.0×10^{8}

Where:

TMDL =Total Maximum Daily Load
LA = Load Allocation (nonpoint source)
WLA =Wasteload Allocation (Point source)
FA =Future Allocation (1% of the TMDL)
MOS =Margin of Safety

Finally the results of the bacterial loading for each source category estimated by the watershed approach were used to partition the load allocation (LA) that would meet water quality standards according to sources, as summarized below:

Source	Source Allocation % of Total Load	Current Load (Counts/Day)	LA (Counts/Day)	Reduction Needed (%)
Livestock	58.98%	2.65E+10	2.30E+08	99.1
Wildlife	39.49%	1.78E+10	1.78E+10	0.0
Human	0.01%	4.50E+06	0	100.0
Pets	1.51%	6.80E+08	0	100.0
Total	100.00%	4.50E+10	1.80E+10	60.0

Margin of Safety

EPA regulations at 40 CFR 130.7 (c)(1) require TMDLs to take into account critical conditions for stream flow, loading, and water quality parameters. This was done in this study by using long-term water quality data that cover different flow regimes and temperatures, and a long-term simulation to estimate the current nutrient and bacteria loads and load reduction targets. To allocate loads while protecting the aquatic environment, a margin of safety (MOS) needs to be considered. For Gargathy Creek, an explicitly MOS of 5% was included in the TMDLs.

Recommendations for TMDL Implementation

The goal of this TMDL is to develop an allocation plan that achieves water quality standards during the implementation phase. Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (WQMIRA) states, in Section 62.1-44.19.7, that the "Board shall develop and implement a plan to achieve fully supporting status for impaired waters".

The TMDL developed for the Gargathy Creek watershed impairments provides allocation scenarios that will be a starting point for developing implementation strategies.

Additional monitoring aimed at targeting the necessary reductions is critical to implementation development. Once established, continued monitoring will aid in tracking success toward meeting water quality milestones.

Public participation is critical to the implementation process. Reductions in non-point source loading are a crucial factor in addressing the problem. These sources cannot be addressed without public understanding of, and support for, the implementation process. Stakeholder input will be critical from the onset of the implementation process in order to develop an implementation plan that will be truly effective.

Public Participation

Public participation was elicited at every stage of the TMDL development in order to receive inputs from stakeholders and to apprise the stakeholders of the progress made. Two public meetings were organized for this purpose. The first public meeting was held on March 28, 2012, to inform the stakeholders of TMDL development process and to obtain feedback. Results of the hydrologic calibration, bacteria source estimates, water quality model, model calibration, and TMDL development were discussed. The second public meeting was held on July 18, 2012 at Accomack-Northampton Planning District Commission. Updated nutrient and bacterial loadings and TMDL results were presented and discussed in the public meeting.

1.0 INTRODUCTION

1.1 Background

Section 303(d) of the Clean Water Act and the United States Environmental Protection Agency's (USEPA's) Water Quality Planning and Management Regulations (40 CFR Part 130) requires states to develop Total Maximum Daily Loads (TMDLs) for waterbodies that are exceeding Water Quality Standards (WQSs). TMDLs represent the total pollutant loading that a waterbody can receive without violating WQSs. The TMDL process establishes the allowable loadings of pollutants for a waterbody that the waterbody can receive without violating WQSs. By following the TMDL process, states can establish controls based on water quality conditions to reduce pollution from both point and nonpoint sources to restore and maintain the quality of their water resources.

Gargathy Creek is located in Accomack County, Virginia, along the Eastern Shore of the Delmarva Peninsula. The Creek drains east to the Atlantic Ocean through Gargathy Inlet. Gargath Creek-Upper (VAT-D03E_GAR01A04), Gargathy Creek - Lower (VAT-D03E_GAR02A04) were listed on the 2006 and 2010 Virginia 305(b)/303(d) Water Quality Assessment Integrated Report (VA-DEQ, 2006; 2010) as having failed to support their designated use of sustaining aquatic life due to violations of Virginia's Dissolved Oxygen (DO) criteria (Table 1.1). The freshwater portion of the Gargathy Creek (Unnamed tributary to Gargathy Creek)(VAT-D03R_GAR01A02) is listed as an impaired waterbody due to a violation of the State's water quality standard for Escherichia coli. Based on the water quality assessment, it does not support its designated use of aquatic life and primary contact recreation (e.g., swimming and fishing). TMDLs have been developed to meet both DO and Escherichia coli standards. This document, upon approval of EPA, establishes a DO TMDL for Gargathy Creek-Upper and –Lower portions of the estuary, and a pathogen (E. coli) TMDL for the freshwater portion of the Gargathy Creek**.**

Table 1.1: Impaired Segments in Gargarthy Creek

Assessment Unit	Water name	Location Description	Cause Category	Cause Name	Size (sq. miles)
VAT-D03E_GAR01A04	Gargathy Creek – Upper	Upper estuarine portion of Gargathy Creek from headwaters downstream to end of DSS condemnation.	5A	Oxygen, dissolved	0.12
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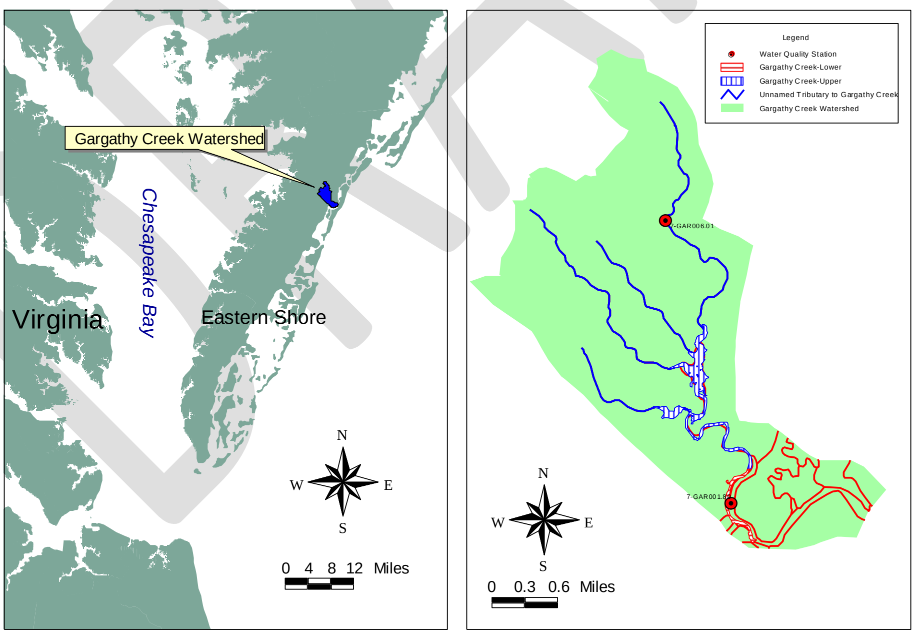
1.2 Listing of Waterbodies under the CWA

WQSs are regulations based on federal or state law that set numeric or narrative limits on pollutants. Water quality monitoring is performed to measure pollutants and determine if the measured levels are within the bounds of the limits set for the uses designated for the waterbody. Waterbodies with pollutant levels that exceed the designated standards are considered impaired for the corresponding designated use (e.g. swimming, drinking, shellfish harvesting, etc.). Under the provisions of §303 (d) of the Clean Water Act (CWA), impaired waterways are placed on the list reported to the EPA. The impaired water list is included in the biennial 305(b)/ 303(d) Water Quality Assessment Integrated Report (WQAIR, VA-DEQ, 2010). Those waters placed on the list require the development of a TMDL and corresponding implementation plan intended to eliminate the impairment and bring the water into compliance with the designated standards.

1.3 Watershed Location and Description

Gargathy Creek is located in Accomack County, along the Eastern Shore of the Delmarva Peninsula (Figure 1.1). The Gargathy Creek watershed is approximately 16.91 km^2 (4,179 acres). It is mainly a forest, agricultural and wetland watershed (approximately 76%). Gargathy Creek can be delineated to three portions, which are Gargathy Creek-Upper, Gargathy Creek-Lower, and the riverine portion of Gargathy (Unnamed tributary to Gargathy (UTGC), one of the main tributaries draining into Gargathy Creek, which drains east to the Atlantic Ocean (Figure 1.2).



Data Source: Virginia Department of the Environmental Quality Map Date: August 2011

Figure 1.1: Location Map of Gargathy Creek, the Impacted Segments, and the Water Quality Stations

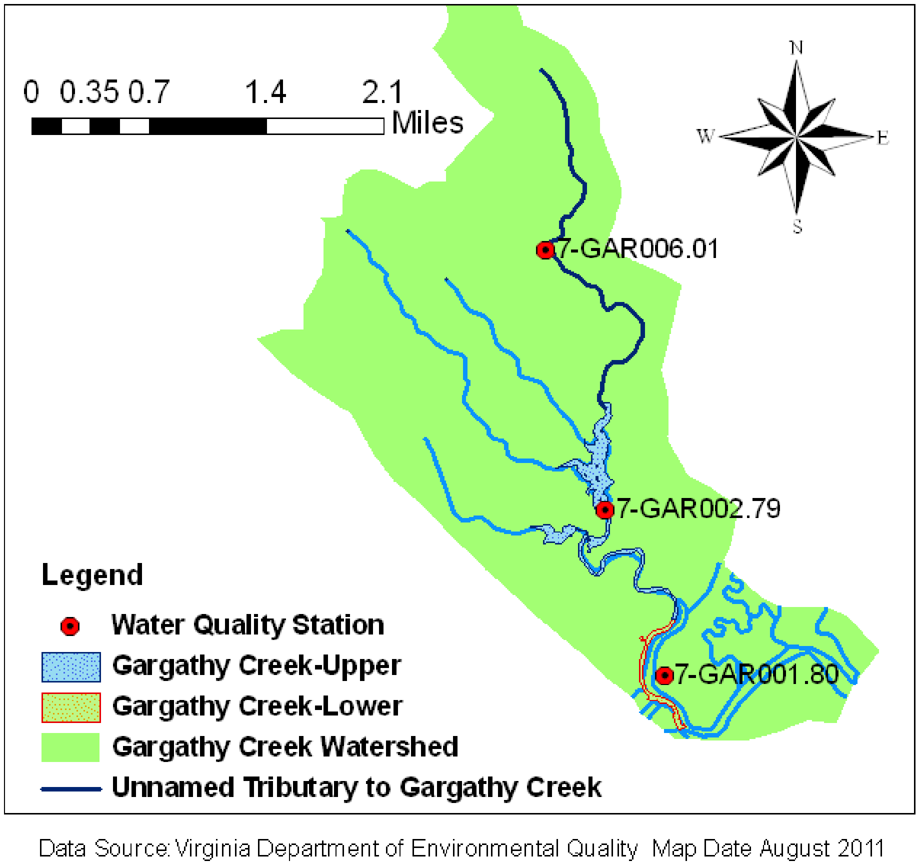


Figure 1.2: Delineation of the Impaired Waterbodies of the Gargathy Creek Watershed

1.4 Designated Uses and Applicable Water Quality Standards

1.4.1 Designation of Uses

According to Virginia WQSs (9VAC25-260-10):

"All State waters, including wetlands, are designated for the following uses: recreational uses, e.g., swimming and boating; the propagation and growth of a balanced, indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them; wildlife; and the production of edible and marketable natural resources, e.g., fish and shellfish."

The state promulgates standards to protect waters to ensure that the uses designated for those waters are met. In Virginia's WQSs, certain standards are assigned by water class, while other standards are assigned to specifically described waterbodies/waterways to protect designated uses of those waters. Virginia has seven waters classes (I through VII) with DO, pH, and temperature criteria for each class (9VAC25-260-50). The identification of waters by class is found in the river basins section tables. The tables delineate the class of waters to which the basin section belongs in accordance with the class descriptions given in 9VAC25-260-50. By finding the class of waters for a basin section in the classification column and referring to 9VAC25-260-50, the DO, pH, and maximum temperature criteria can be found for each basin section. Gargathy Creek is considered as a Class II water, "Estuarine Water (Tidal Water-Coastal Zone to Fall Line)" (9VAC25-260-50).

Figure 1.2 illustrates the delineation of the impaired segments. The riverine tributary of Gargathy Creek does not support the recreational and aquatic designated use due to violations of *E. coli* criteria. The upper and lower portions of Gargathy Creek do not support the aquatic designated use due to violations of the DO criteria.

1.4.2 DO Criteria

DO is a basic requirement for a healthy aquatic ecosystem. Most fish and beneficial aquatic insects "breathe" oxygen dissolved in the water column. Most desirable fish species suffer if DO concentrations fall below 3 to 4 mg/l. Many fish and other aquatic organisms can recover from short periods of low DO availability. When oxygen drops to about 4 mg/l, fish will begin to feel stressed and move away from the area. Below 3 mg/l, fish kills may be observed and shellfish begin to shut down. At about 2 mg/l or lower, animals living in the sediments will start to die. Exposure to less than 2 mg/l oxygen for prolonged episodes may kill most organisms, leaving only air-breathing insects and anaerobic organisms. When a body of water experiences low levels of oxygen, the condition is known as hypoxia. When oxygen levels drop to virtually none, the condition is called anoxia.

According to 9VAC25-260-50, the numerical criterion for DO for Class II waters is a minimum of 4.0 mg/l and a daily average of 5.0 mg/l.

1.4.3 Bacteria Standard

Effective February 1, 2010, VADEQ specified a new bacteria standard in 9 VAC 25-260-170. These standards replaced the existing fecal coliform standard of 9 VAC 25-260-170 (http://lis.virginia.gov/cgi-bin/legp604.exe?000+reg+9VAC25-260-170). For a non-shellfish supporting waterbody to be in compliance with Virginia bacteria standards for primary contact recreation in a saltwater or transition zone, the current criteria are as follows:

"E.coli bacteria shall not exceed a monthly geometric mean of 126 CFU/100 ml in freshwater. If there are insufficient data to calculate monthly geometric means in freshwater, no more than 10% of the total samples in the assessment period shall exceed 235 E.coli CFU/100 ml."

1.5 Impairment Listing

The VA-DEQ has one water quality station (7-GAR006.01) within the riverine portion of Gargathy, and two stations (7-GAR002.79 and 7-GAR001.80) in the Gargathy Creek upper and lower portions of the Creek (see Figure 1.2 for station locations). There are no DO data at Station 7-GAR002.79. Sufficient exceedances of Virginia's WQSs for DO minimum and enterococci maximum were recorded at the stations to assess the segments of Gargathy Creek as not supporting of the CWA's aquatic life and recreation use support goal in Table 1.2. The designated uses, impairments, and criteria Gargathy Creek listed segments are summarized in Table 1.3.

Table 1.2: Exceedances of the Water Quality Criteria (1997-2011) of Gargathy Creek

Stream Name	Station ID	Impairment	Number of Samples	Number of Exceedances	Percentage Exceedance
Gargathy Creek-Upper	7-GAR002.79	DO	No		
Gargathy Creek-lower	7-GAR001.08	DO	80	13	16.2%
Riverine Gargathy	7-GAR006.01	E. coli	6	2	33.3%

Table 1.3: The Water Types, Designated Uses, Impairments, WQC, and List Years for Gargathy Creek

Stream Name	Water Type	Designated Use	Impairment	Criteria	List Year
Gargathy Creek-upper	Tidal	Aquatic life	DO	Minimum >4 (mg/l)	1996 ~2011
Gargathy Creek-lower	Tidal	Aquatic life	DO	Minimum >4 (mg/l)	1994 ~2011
Riverine Gargarthy	Nontidal	Recreation	E. coli	Minimum >235 (CFU/100ml)	2006 ~2011

2.0 WATERSHED CHARACTERIZATION

2.1 Topology, Soil, and Climate

The Gargathy Creek watershed, located along Virginia's Eastern Shore, is in the lowland sub-province of the Coastal Plain province. Latest Tertiary and Quaternary sand, silt, and clay, which cover much of the Coastal Plain, were deposited during interglacial highstands of the sea under conditions similar to those that exist in the modern Chesapeake Bay and its tidal tributaries (http://www.wm.edu/geology/virginia/provinces/coastalplain/coastal_plain.html). The soils in the watershed range from moderately drained to slow infiltration rate.

As part of the Tidewater Climate Region, the Gargathy Creek watershed experiences average January temperatures of 35-48 ^{o}F and average July temperatures of 71-85 ^{o}F. Average annual precipitation is 41.3 inches. It is influenced by stream discharge, groundwater seepage and surface runoff.

2.2 Landuse

The landuse characterization for the Gargathy Creek watershed was based on the land cover data from the Virginia National Land Cover Data (NLCD) 2006 Landuse Dataset (Figure 2.1). The brief descriptions of landuse classifications in the watershed, land area, and percentage are presented in Table 2.1. Dominant landuses in the watershed were found to be agricultural (51%) and forest (27%), which account for 78% of the total land area in the watershed (Figure 2.2).

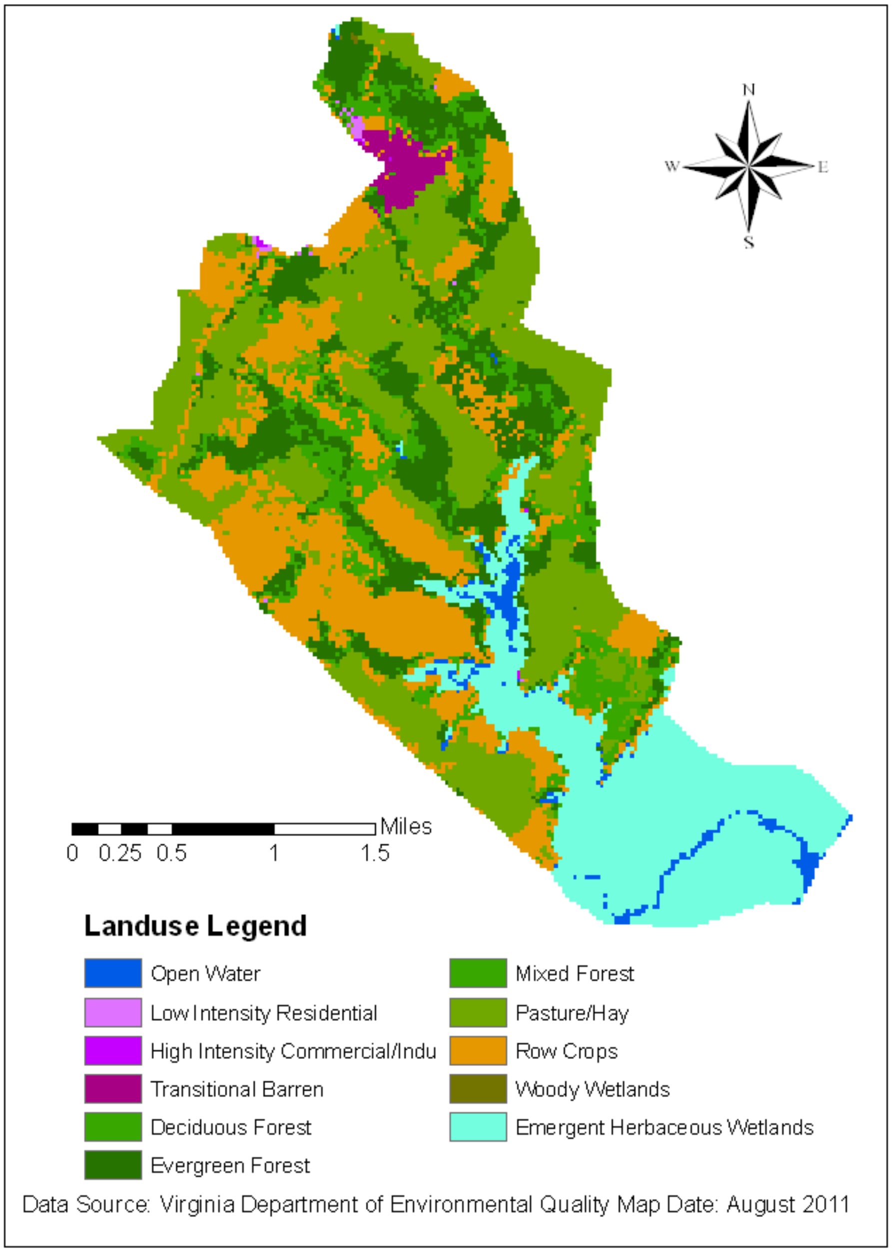


Figure 2.1: Landuse of Gargathy Creek Watershed

Table 2.1: Landuse Descriptions and Percentages of the Gargathy Creek Watershed

General Landuse	Specific Landuse	Acres	% of Watershed	% of Total
Forest	Deciduous Forest (Areas dominated by trees where 75% or more of the tree species shed foliage simultaneously in response to seasonal change)	283.3	6.53	27.00
	Mixed Forest (Areas dominated by trees where neither deciduous nor evergreen species represent more than 75% of the cover present)	201.1	4.63	
	Evergreen Forest (Areas characterized by trees where 75% or more of the tree species maintain their leaves all year; Canopy is never without green foliage)	687.2	15.84	
Agriculture	Row Crops (Areas used for the production of crops, such as corn, soybeans, vegetables, tobacco, and cotton)	938.7	21.64	49.85
	Pasture/Hay (Areas of grasses, legumes, or grass-legume mixtures planted for livestock gra-zing or the production of seed or hay crops)	1224.1	28.21	
Water	Open Water (Areas of open water, generally with less than 25% or greater cover of water)	78.5	1.81	21.43
Wetlands	Emergent Herbaceous Wetlands (Areas where perennial herbaceous vegetation accounts for 75-100% of the cover and the soil or substrate is periodically saturated with or covered with water)	849.8	19.59	
	Woody Wetlands (Areas where forest or shrubland vegetation accounts for 25-100% of the cover and the soil or substrate is periodically saturated with or covered with water)	1.1	0.03	
Developed	Low Intensity Residential (Includes areas with a mixture of constructed materials and vegetation. Constructed materials account for 30-80% of the cover. Vegetation may account for 20-70% of the cover. These areas most commonly include single-family housing units. Population densities will be lower than in high intensity residential areas)	9.3	0.22	0.44

	Commercial/Industrial/Transportation (Includes infrastructure (e.g. roads, railroads, etc.) and all highways and all developed areas not classified as High Intensity Residential)	9.3	0.22	
Barren	Transitional Barren	62.7	1.45	1.45
Total		4338.8	100	100

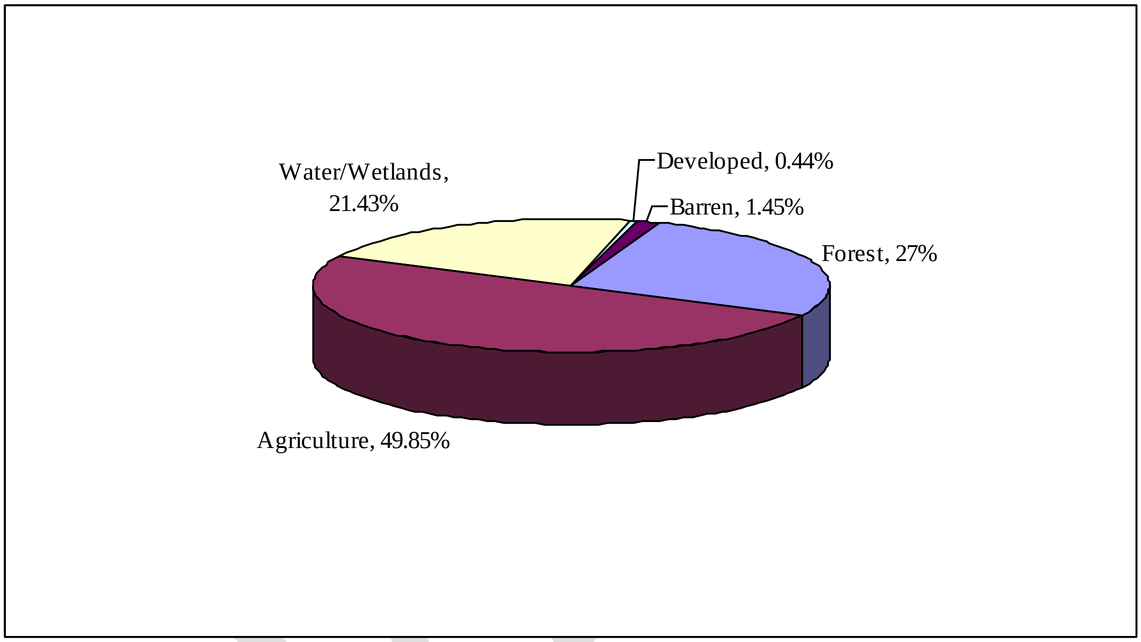


Figure 2.2: Percentage Landuse Group of the Gargathy Creek Watershed

2.3 Water Quality Conditions

The VA-DEQ performs water quality monitoring throughout Virginia to determine if WQSs are being met for the designated uses of the corresponding waters. Samples have been taken at the two water quality monitoring stations in Gargathy Creek since 1997 (Figure 1.2). A summary of the data is listed in Table 2.2.

Fecal bacteria, *E. coli* and enterococci, were assessed as indicator organisms for predicting human health impacts. Studies found that the highest correlation to gastrointestinal illness was linked to elevated levels of *E. coli* and enterococci in fresh water (enterococci in salt water). Currently VA-DEQ analyzes the fecal coliform, enterococci, and *E. coli* concentrations in water samples by using the membrane filtration method. This method usually has a maximum detection limit of 8,000 counts/100 ml, but the upper limit can be increased to 16,000 counts/100 ml if concentrations are expected to be high. The minimum detection limits for fecal coliform, enterococci, and *E. coli* are 100, 10, and 25 counts/100 ml, respectively. Enterococci are used for this assessment.

Table 2.2: The Water Quality Observations in Gargathy Creek

Station	Latitude	Longitude	Parameter	Date	# of Observations
7-GAR006.01	37.81278	-75.57194	DO	04/2000-10/2006	9
			TN		0
			NH_4^+	04/2000-10/2006	9
			NO_{23}^-	04/2000-10/2006	9
			TP	04/2000-10/2006	9
			PO_4^{3-}	04/2000-10/2006	9
			BOD_5	04/2000-10/2006	9
			pH	04/2000-10/2006	9
			Fecal Coliform	04/2000-10/2006	9
			Enterococci	10/2002-10/2003	2
			E. coli	10/2002-10/2006	6
			DO	01/1997-06/2011	80
7-GAR001.80	37.77583	-75.55861	TN	08/2003-06/2011	47
			NH_4^+	01/1997-06/2003	33
			NO_{23}^-	01/1997-06/2003	35
			TP	01/1997-06/2011	82
			PO_4^{3-}	01/1997-06/2003	35
			BOD_5	01/1997-07/2001	23
			Chl *a*	08/2001-04/2011	58
			pH	01/1997-06/2011	83
			Fecal Coliform	01/1997-06/2011	80
			Enterococci	08/2002-06/2011	54
			E. coli	08/2002-04/2004	11

2.3.1 Dissolved Oxygen

Oxygen concentrations in a water column fluctuate under hydrological conditions. Severe oxygen depletion may result from activities that introduce large quantities of nutrients into surface waters that promote the excessive growth of algae. When the algae die, or other organic material gets introduced to the system, the bacteria decomposition process consumes large quantities of oxygen, which can result in a net decline in DO concentrations in the water. Other factors (such as temperature) influence the amount of oxygen dissolved in water as well. The process of nutrient enrichment in aquatic ecosystems is called eutrophication. Human activities can greatly accelerate eutrophication by increasing the rate at which nutrients and organic substances enter aquatic ecosystems from their surrounding watersheds. Agricultural runoff, urban runoff, leaking septic systems, sewage discharges, eroded stream banks, and similar sources can increase the flow of nutrients and organic substances into aquatic systems.

For Gargathy Creek, most of the DO samples were collected bi-monthly at Station 7-GAR001.80, from 1997-2011. Figure 2.3 shows all the available DO observations from 1997 to 2010 at Station 7-GAR001.80. There are thirteen observations below the water quality criterion of 4 mg/l minimum. The two lowest DO values of 2.75 mg/l and 2.5 mg/l were recorded on 08/09/2005 and 08/03/2006. Figure 2.3 shows the monthly distribution of DO at this station. It shows that low DO occurs in summer and the lowest DO occurs in August. Correlation analysis between DO and nutrients, pH, algae, and temperature show that DO is highly correlated to temperature and ammonium (Figure 2.5). It is weakly correlated to phosphorus. The correlation between algae and DO is weak. This indicates that low DO is highly controlled by nonpoint sources and bottom sediment oxygen demand (SOD). The measurement location is surrounded by salt marshes. Organic materials and relatively low DO water output from salt marsh due to higher respiration also add pressure to low DO conditions of the Creek (Layman et al., 2000; Smith and Albe, 2003).

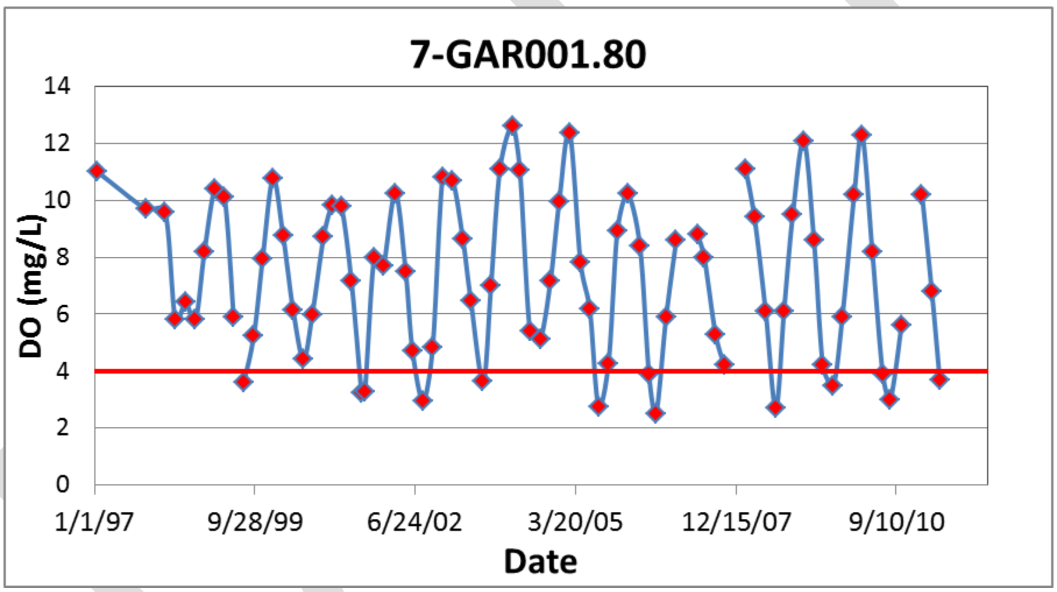


Figure 2.3: DO Observations from 1999 to 2010 at Station 7-GAR001.80 Located in Gargathy Creek-Lower. Red Line denotes the WQC of DO Minimum

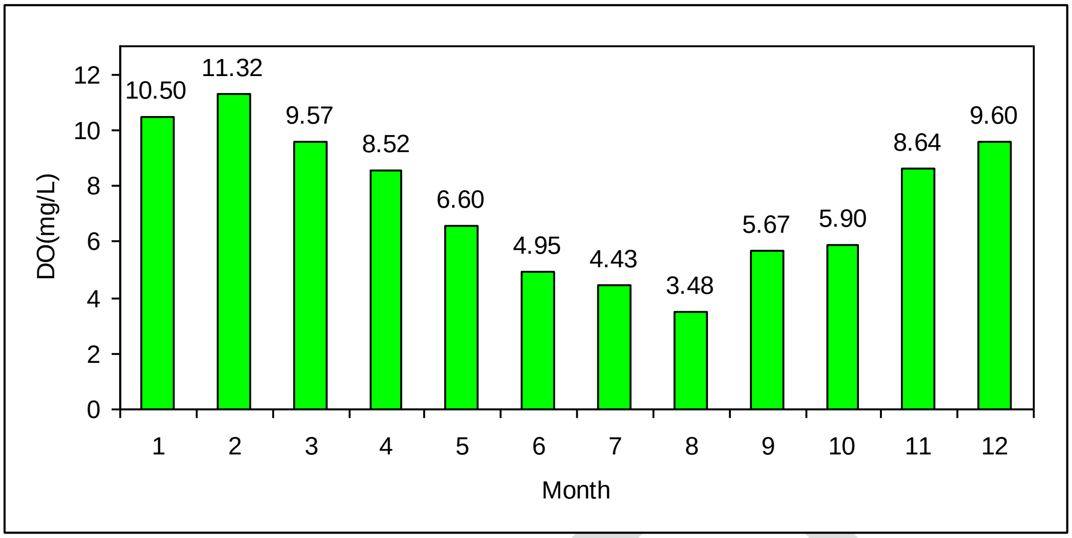


Figure 2.4: Averaged Monthly DO at Station 7-GAR001.80 in Gargathy Creek (1997-2011)

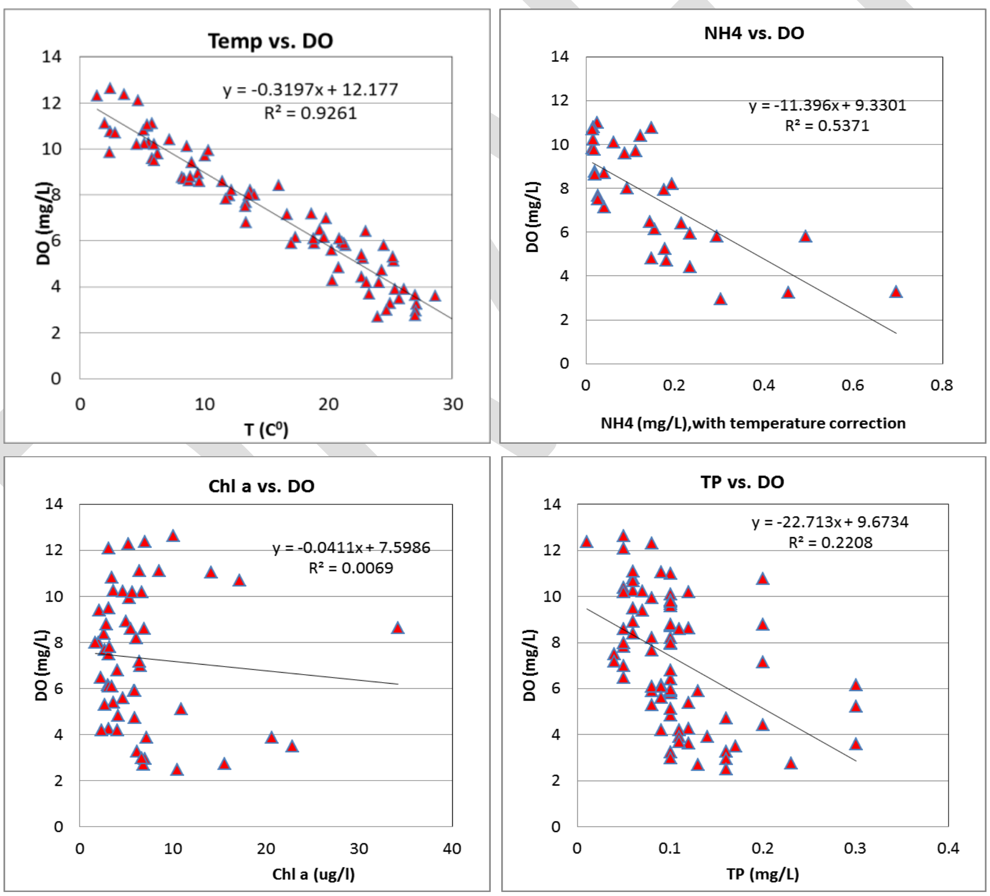


Figure 2.5: DO Correlation Analysis Results

2.3.2 Biological Oxygen Demand and Chemical Oxygen Demand

Biochemical oxygen demand, BOD, is a measure of the amount of oxygen consumed in the biological processes that break down organic matter in water. BOD is used as an indirect measure of the concentration of biologically degradable material present. It usually reflects the amount of oxygen consumed in five days by biological processes breaking down organic matter. The test is considered to represent the amount of organic carbon (OC) available in the sample, but may include some nitrogenous-based organic material unless the consumption of these materials is chemically inhibited.

BOD can also be used as an indicator of the pollutant level, where the greater the BOD, the greater the degree of pollution. BOD concentrations in streams depend on the natural environment and dynamic conditions of a waterbody. In natural, unpolluted waterbodies, the BOD can be less than 5 mg/l (Boyd, 2000). Limited BOD samples were collected bi-monthly from September 1997 to September 2007 at the one monitoring station (Figures 2.6). Most of the observations were below the detection limit of 2 mg/l, indicating a low short-term biodegradable organic level in the waterbody. The high BOD level occurrences of 3 mg/l were recorded in April 1998 at Station 7-GAR001.80.

Chemical oxygen demand (COD) is a measure of the total amount of oxygen required to oxidize organic matter to carbon dioxide and water. It is determined by oxidation of the organic matter with potassium dichromate and sulfuric acid. It is often used as a rapid way to assess BOD. The BOD and COD are roughly equal to each other in a waterbody characterized by highly decomposable organic matter. On the other hand, COD may be significantly higher than BOD in an environment with organic matter is resistant to quick decay. At Station 7-GAR001.80, no COD measurements have been done.

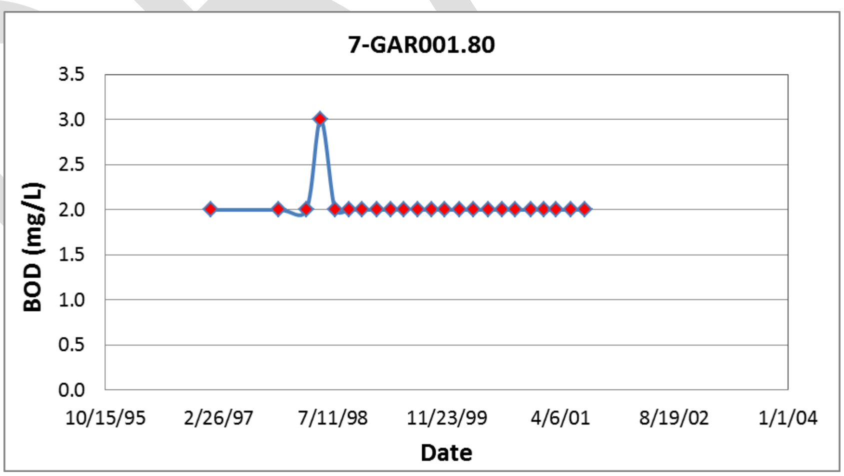


Figure 2.6: BOD Observations from 1997 to 2010 at Station 7-GAR001.80.

2.3.3 Chlorophyll *a*

Chlorophyll *a* is a green pigment found in most algae and cyanobacteria, allowing them to convert sunlight into organic compounds in the process of photosynthesis. Its abundance is a good indicator of the amount of algae present in water. Excessive quantities of chlorophyll *a* can indicate the presence of algae blooms, in which unconsumed algae sink to the bottom and decay, using up the oxygen required by other plants and benthic organisms. As chlorophyll *a* levels increase, the amount of sunlight reaching underwater grasses declines as well. Figure 2.7 shows the available observations of chlorophyll *a* concentrations for Gargathy Creek. In general, the concentrations were between 1 and 30 ug/l, which usually indicates that nutrients have an impact on algae in the tidal portion of the Creek.

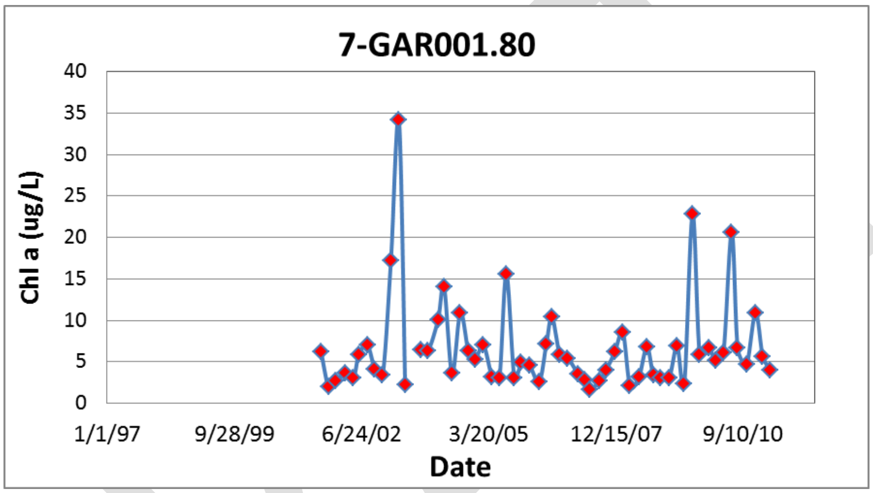


Figure 2.7: Chlorophyll-*a* Concentrations at Station 7-GAR001.80 Located in the Gargathy Creek-Lower

2.3.4 Nutrients

The nutrients, nitrogen and phosphorus, are elements, and are essential building blocks for plant and animal growth. The measurement frequencies of the nitrogen and phosphate are the same as DO at the three mooring stations. The water samples of nitrogen and phosphate were collected at Station 7-GAR001.80.

Nitrogen exists in water both as inorganic and organic species, and in dissolved and particulate forms. Total dissolved inorganic nitrogen (DIN, includes NO_3^-, NO_2^-, NH_4^+, and NH_3) is a measure of all forms of DIN present in a water sample, which are essential nutrients for plants to uptake. On the other hand, organic nitrogen is undergoing ammonification to become NH_4^+, which oxidizes to NO_2^-. High concentrations can be observed for the stream with point source discharging nitrogen. For Gargathy Creek, Total Organic nitrogen and ammonium (TKN) ranges from 0.5 -2 mg/L and NH_4^+ ranges from 0.05-0.5 mg/l. TN ranges from 0.2 -2.2 mg/l. NO_{23} ranges from 0.05-0.5 mg/L at Station 7-GAR001.8. This value is lower than the concentration in its upstream at Station 7-GAR006.01, which ranges from 2-3 mg/l. The nutrient level is high enough to stimulate algae growth and causes eutrophication. Figures 2.8-2.11 show the nitrogen distribution for TKN, TN, NH_4^+ and NO_{23}. A large portion of nitrogen can be discharged into the stream from the watershed through leaching and infiltration. A large amount of DO can be consumed through the nitrogen oxidation process by oxidizing ammonia to nitrite when organic and ammonia nitrogen exists in the nonpoint sources.

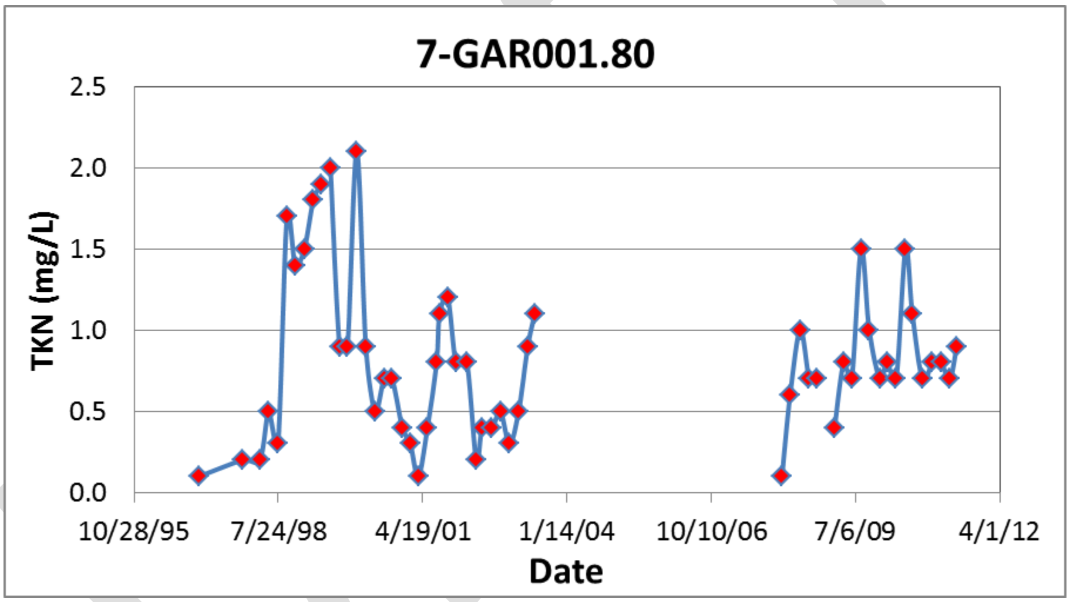


Figure 2.8: TKN at Station 7-GAR001.80 in Gargathy Creek-Lower

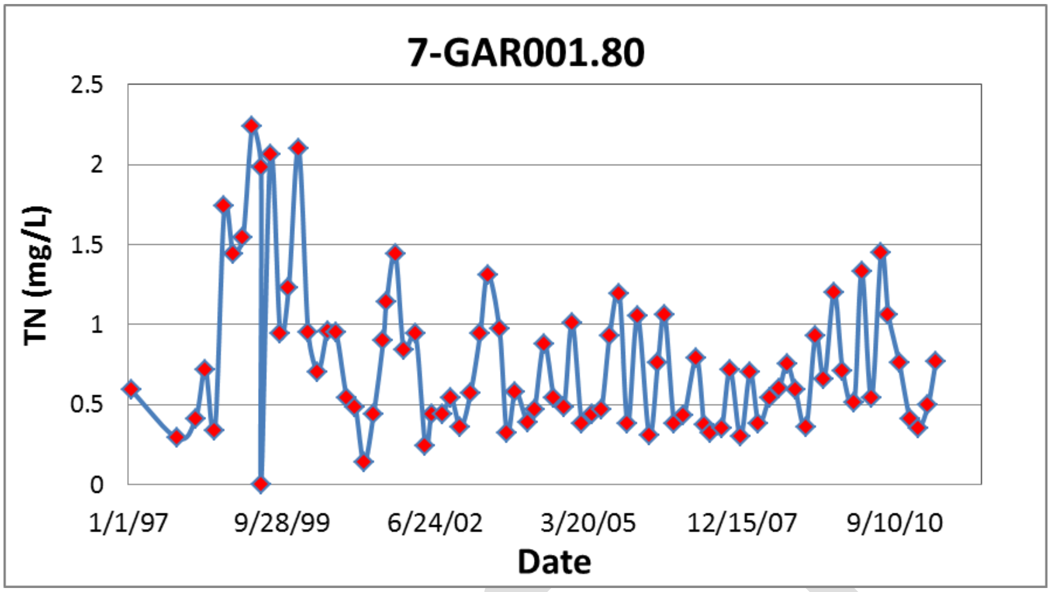


Figure 2.9: TN at Station 7-GAR001.80 in Gargathy Creek-Lower.

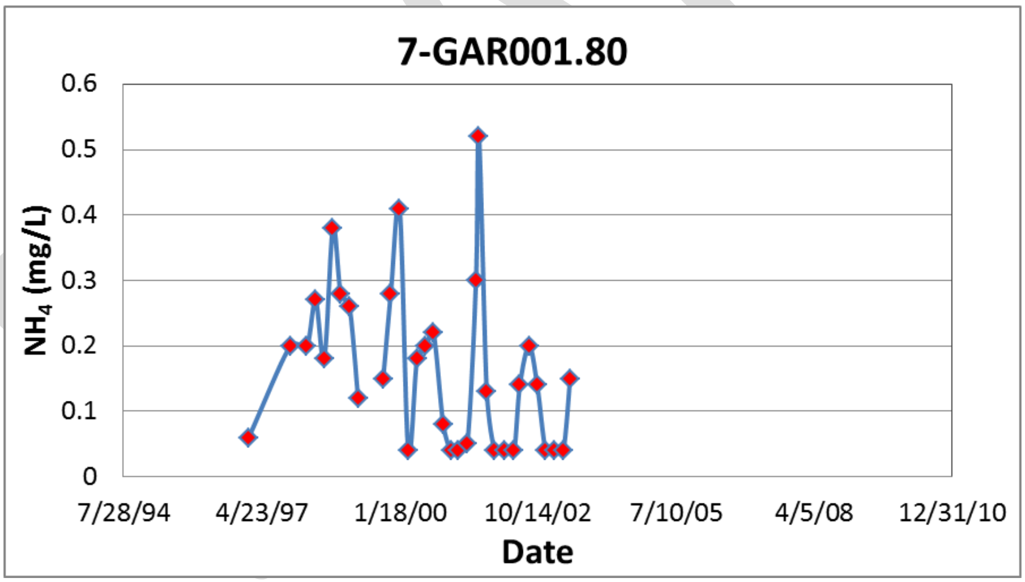
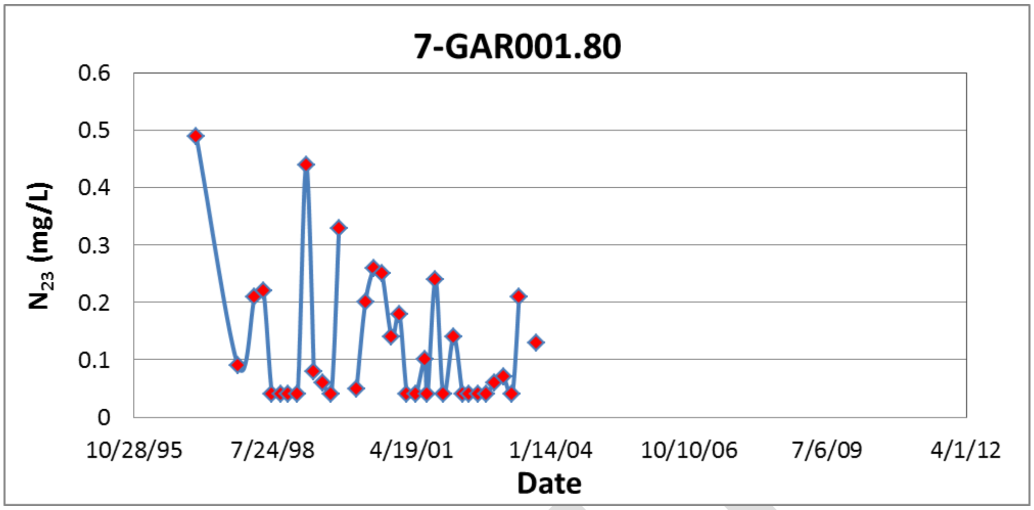


Figure 2.10: NH_4 at Station 7-GAR001.80 Located in Gargathy Creek-Lower.



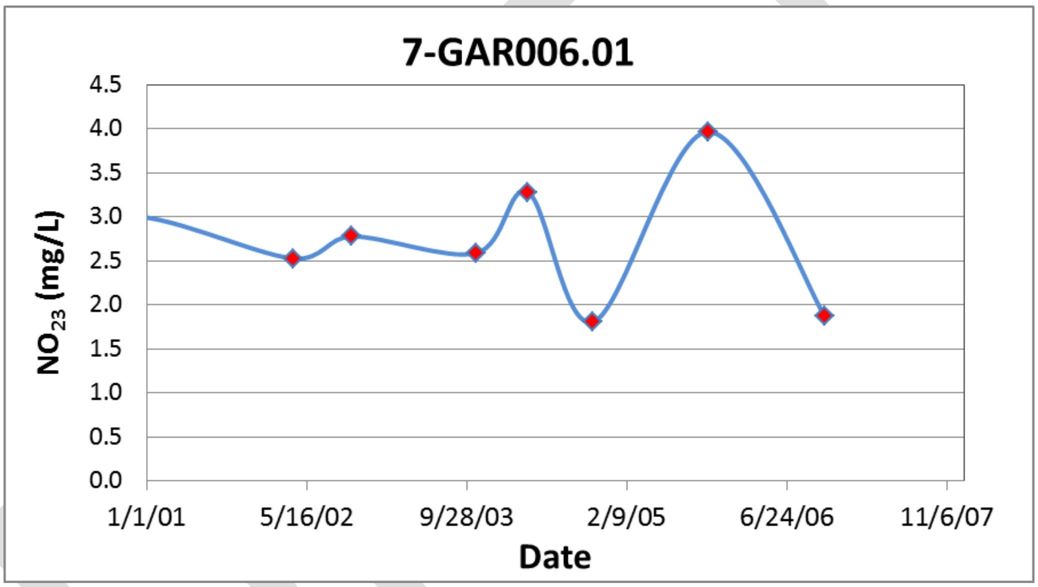


Figure 2.11: NO_{23} at Station 7-GAR006.80 and 7-GAR006.01 located in Gargath Creek-Lower and Riverine portion of Gargathy Creek.

Phosphorus is found in nucleic acids and certain fats (phospholipids). It is a common element of igneous rocks. It is found in waterbodies in dissolved and particulate forms. Total phosphorus (TP) is a measure of all the various forms of phosphorus (dissolved and particulate) found in water. For a mesotrophic waterbody, TP ranges from 10 to 20 mg/l (Thomann and Mueller, 1987). Figure 2.12 shows the TP concentration at Station 7-GAR001.80 that ranges from 0.05-0.3 mg/l. The highest TP concentration did not exceed 0.3 mg/l.

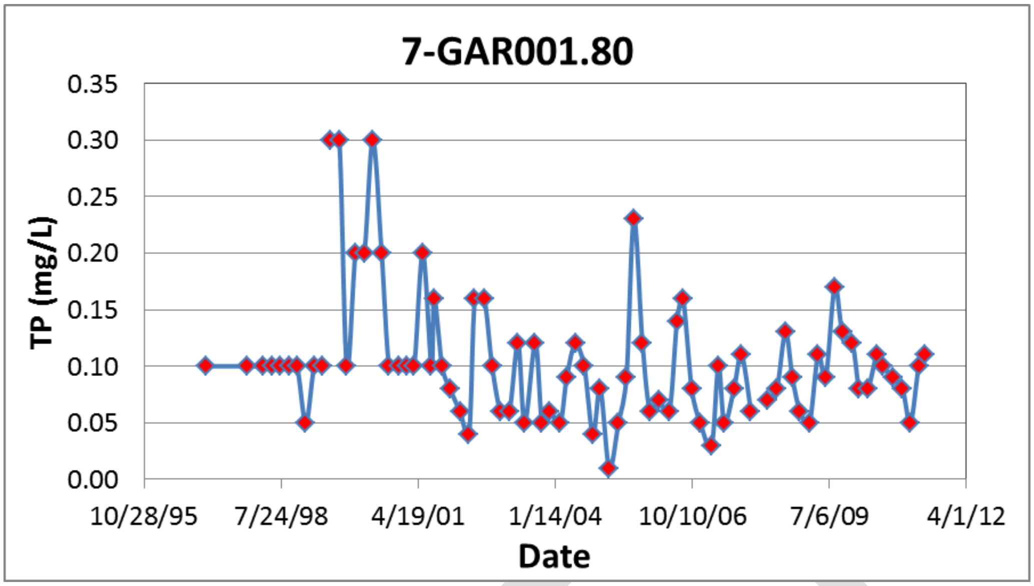


Figure 2.12: TP Concentrations at Station 7-GAR001.80 in Gargathy Creek-Lower.

2.3.5 Temperature, Salinity, and pH

Temperature, salinity, and pH values for Gargathy Creek at Station 7-GAR001.80 are shown in Figures 2.13-2.15. A wide seasonal temperature variation is typical in the stream. Summer temperatures reached 30 degrees C and winter low temperatures were about 0 degree C. The high temperature corresponded to the low DO in summer (Figure 2.13). The average salinity value in lower reach of Gargathy Creek was above 30 ppt (Figure 2.14), indicating it is highly influenced by tide. The pH values varied between 7.0 and 8.2 in Gargathy Creek, which is within the optimum range of 6.5-9.0 for fish and other aquatic life (Figure 2.15).

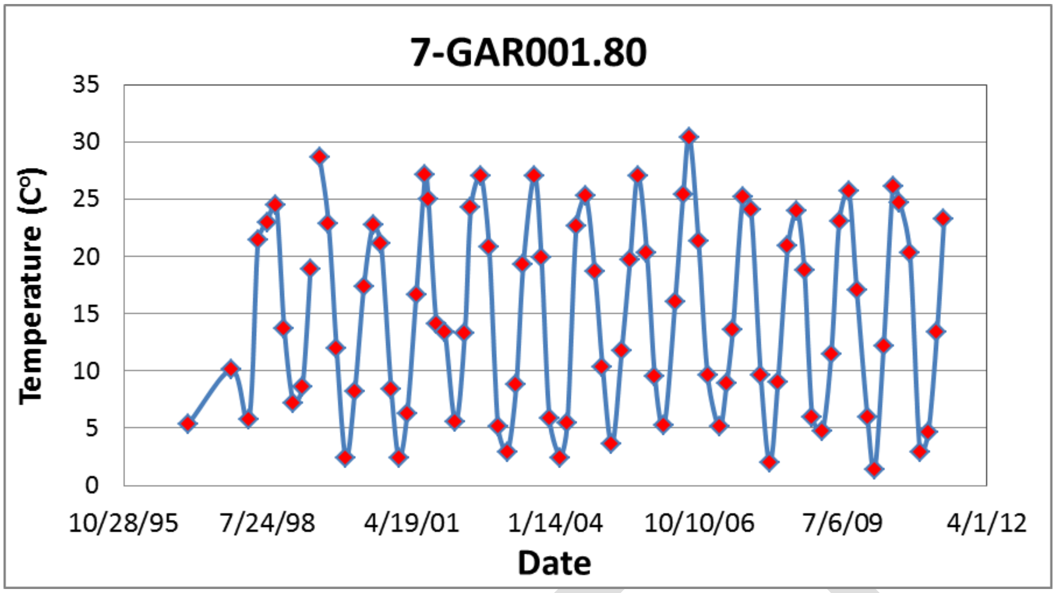


Figure 2.13: Temperature Variations in Gargathy Creek-Lower

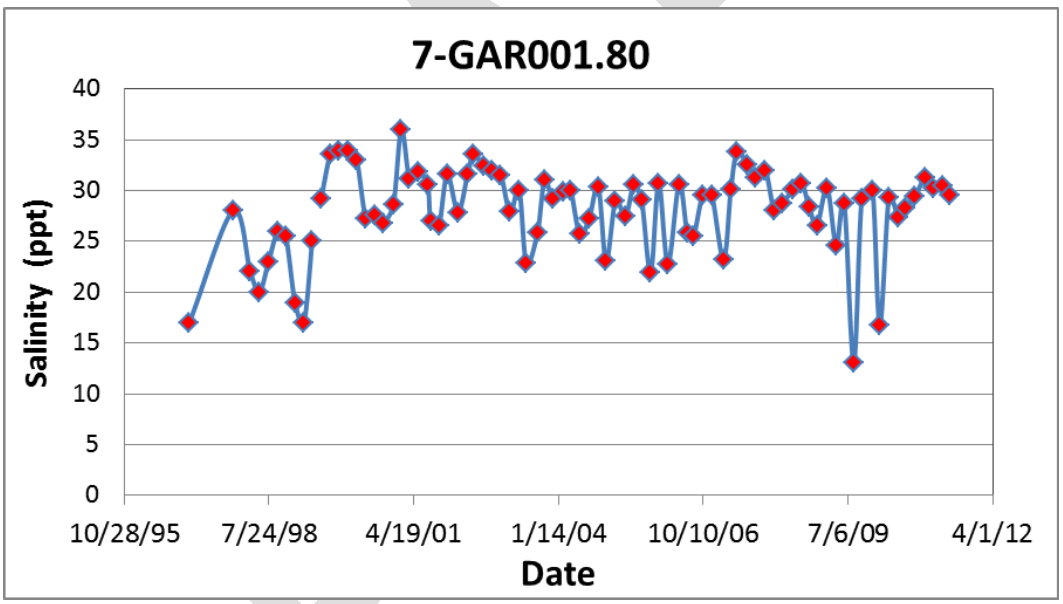


Figure 2.14: Salinity Variations in Gargathy Creek-Lower

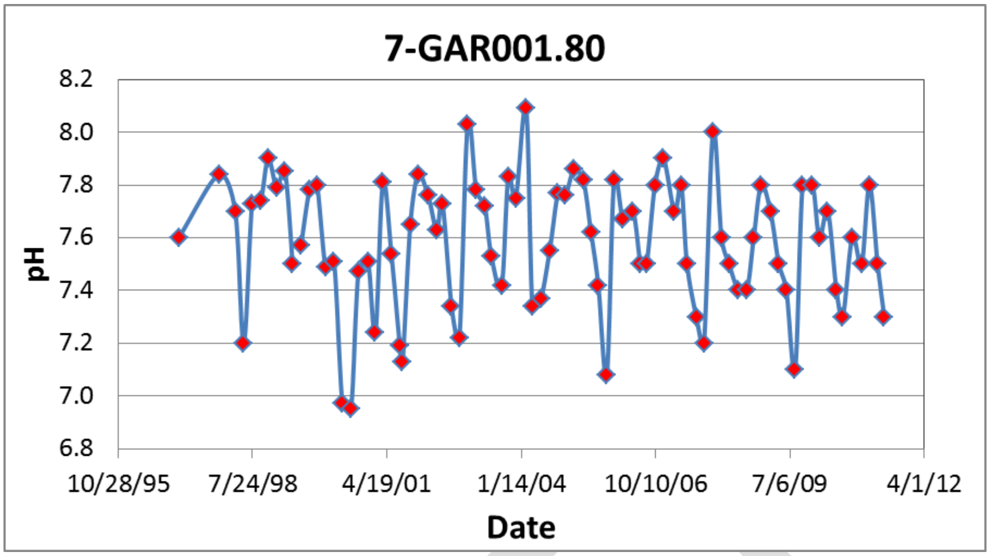
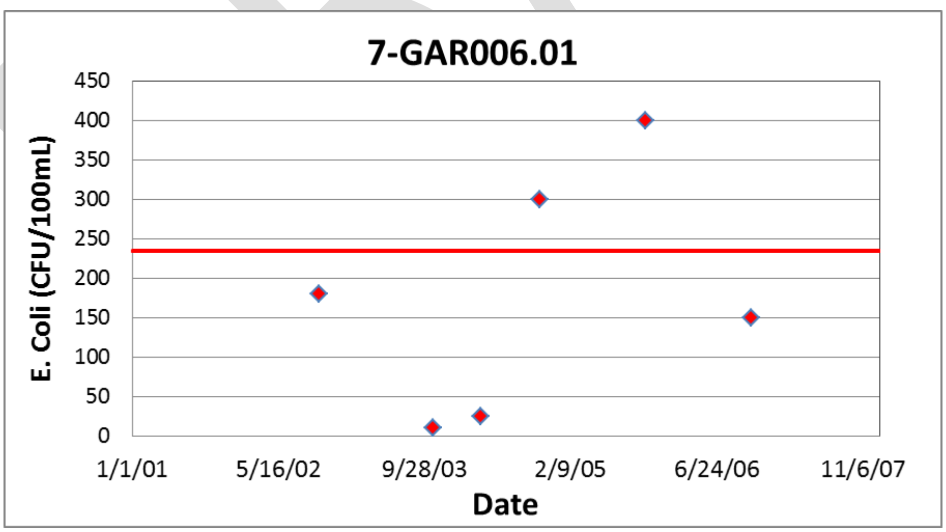


Figure 2.15: pH Values in Gargathy Creek-Lower

E. coli was measured at Station 7-GAR006.01 in the riverine portion of Gargathy Creek between 2002 to 2007. Two observations out of five show violations of the water quality standard of an instantaneous maximum value of 235 CFU /100 ml. The geomean of observations is 96.5 CFU/100 ml. Not enough data was available to compute a monthly geomean for this station. Figure 2.16 shows both *E. coli* and fecal coliform concentration distribution at Station 7-GAR006.01 in the Gargathy Creek.



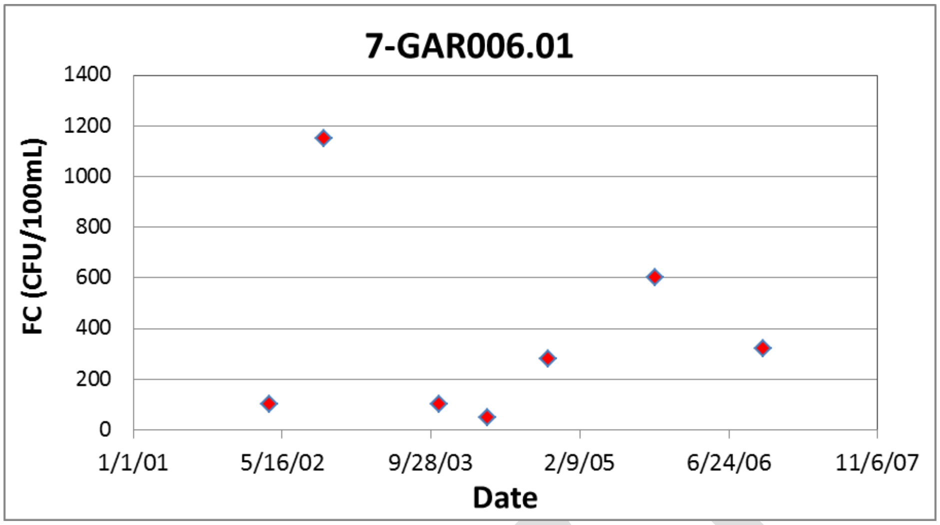


Figure 2.16: E. coli and Fecal Coliform values in the freshwater portion of the Gargathy Creek

2.3.6 Summary of Data Analysis

Gargathy Creek is a narrow stream. The stream is surrounded by forest and agricultural land with large marshes adjacent to the stream. Runoff from adjacent farmlands, forestland, and marshes can discharge to the stream. There is no point source facility with permitted nutrient levels or bacteria that directly discharges to Gargathy Creek. Because of the influence of tide, a large amount of carbon and nutrients transported from upstream and the adjacent watershed will be deposited to the bottom. The light condition appears sufficient for algae growth. As algae die and deposit to the bottom, the DO consumption in summer will increase.

A summary of the statistics for water quality parameters is listed in Table 2.4. In general, the averaged TN and TP were 0.76 and 0.10 mg/l. The mean TN value is on the same order of the EPA-recommended nutrient level of 0.7 mg/l, but high values of 1.5 -2 mg/l were observed. A high mean concentration of nitrate of 2.65 mg/L was observed in the freshwater portion of the Creek. TP values are higher than the EPA-recommended nutrient level of 0.03 mg/l. Both TN and TP were higher than the screening level of water quality assessment guideline for Class VII, Swamp Water. The averaged pH value was slightly higher than 6. The results indicate that low DO in the Creek is mainly caused by the deposition of organic matter resulting in high sediment oxygen demand (SOD). Large marsh areas near the mouth of the Creek also add pressure for the Creek due to high respiration in the marsh and diurnal DO fluctuation, which is caused by photosynthesis of benthic algae, phytoplankton and submerged aquatic vegetation during daytime, and decreases after nightfall when high respiration occurs and DO consumption becomes high (Smith and Able, 2003; Layman et al., 2000).

Table 2.3: Summary of Water Quality Parameters

Station	Parameter	Mean	Standard Deviation	[1]Background Value for Natural Condition	Values EPA Recommended
7-GAR001.80	DO (mg/L)	7.31	2.77		
	TN (mg/L)	0.76	0.47	<1.0	0.71
	NH_4^+ (mg/L)	0.17	0.12		
	NO_{23}^- (mg/L)	0.13	0.12	<0.6	
	TP (mg/L)	0.10	0.06	<0.1	0.03
	PO_4^{3-} (mg/L)	0.05	0.03		
	BOD_5 (mg/L)	2.04	0.21		
	Chl *a* (ug/L)	6.67	5.73		
	pH	7.58	0.25		
	Fecal Coliform	46	159.27		
	Entercococci	78	281.40		
	E. coli	12	11.82		
7-GAR006.01	DO (mg/L)	8.70	1.40		
	TN (mg/L)	3.03	0.11	<1.0	0.71
	NH_4^+ (mg/L)	0.04	0		
	NO_{23}^- (mg/L)	2.65	0.71	<0.6	
	TP (mg/L)	0.10	0	<0.1	0.03
	PO_4^{3-} (mg/L)	0.04	0.02		
	BOD_5 (mg/L)	2.33	0.71		
	Chl *a* (ug/L)				
	pH	7.29	0.22		
	Fecal Coliform	378	343.03		
	Entercococci	260	212.13		
	E. coli	178	152.70		

[1]Water Quality Assessment Guidance Manual, VA-DEQ, 2008, http://www.deq.virginia.gov/waterguidance/wqam.html

3.0 SOURCE ASSESSMENT

3.1 General

All aquatic plants and algae require nutrients for growth. In aquatic environments, nutrient availability usually limits algal growth. When these nutrients are introduced into the estuary at higher rates, aquatic plant and algae productivity may increase dramatically. This in return results in more organic materials being added to the system, which eventually die and decay. The decaying organic matter depletes the oxygen supply available to aquatic organisms. This process, referred to as eutrophication, may adversely affect the suitability of the water for other uses. Depleted oxygen levels, especially in bottom waters where dead organic matter tends to accumulate, can reduce the quality of fish habitat and encourage the propagation of fish that are adapted to less oxygenated environments or the migration of fish to surface waters.

A primary component of DO and pathogen TMDLs development for Gargathy Creek is the evaluation of potential sources of nutrients and pathogen in the watershed. The watershed approach was applied for the source assessment. Landuse data together with human population, wildlife, fertilizer application, atmospheric deposition, manure application etc. were used for the assessment. Sources of information that were used in evaluating potential pollutant sources included the VA-DEQ, the Virginia Department of Conservation and Recreation (VA-DCR), the Virginia Department of Game and Inland Fisheries (VADGIF), the Virginia Department of Health (VDH), US Department of Agriculture (USDA) agriculture census data, public participation, watershed studies, stream monitoring, published information, and best professional judgment.

The potential pollutant sources in the watershed can be broken down into point and nonpoint sources. Point sources are permitted pollutant loads derived from individual sources and discharged at specific locations. There is no known point source within the Gargathy Creek watershed. Nonpoint sources are from various sources over a relatively large land area, which are the dominant pollutant sources in the watershed.

3.2 Population Number Summaries

Population numbers for humans, dogs, livestock, and wildlife are shown in Table 3.1. The human population was derived from US Census Bureau data (US Census Bureau, 2010) and estimated based on watershed area and landuses for the Gargathy Creek watershed with respect to the county watershed area for urban landuse. National Agriculture Statistics Survey data were used to calculate the livestock values. The population number calculation details are described in Appendix B.

Table 3.1: Human, Dog, Livestock, and Wildlife Populations in Gargathy Creek

		Totals
Humans		494
Dogs		139
Cat**(unused)		157
Livestock	Cattle	12
	Swine	0
	Chickens	134390
	Horses	7
	Sheep	6
Wildlife	Ducks	9
	Geese	96
	Deer	200
	Raccoons	101
	Muskrat	361
	Nutria	212

3.3 Septic System Inputs

Conventional septic tank systems are only effective where the soil is adequately porous to allow percolation of liquids, and the groundwater level is low enough to avoid contamination. Leaking pipes or treatment tanks (i.e., leakage losses) can allow wastewater to return to the groundwater, or discharge to the surface, without adequate treatment. Leaking septic systems are a source of nutrients and bacteria. There are a total of 313 septic systems in the Gargathy Creek watershed (Figure 3.1). Using a failure rate of 12% based on data from the Eastern Shore region and the literature, the number of failed systems is approximately 38.

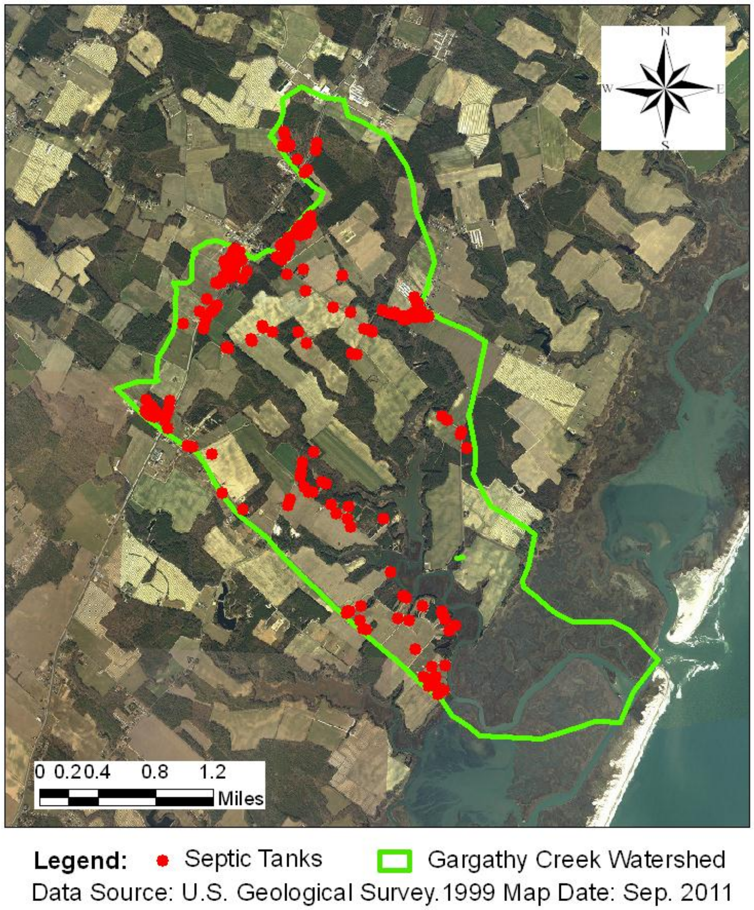


Figure 3.1: Septic System Locations in the Gargathy Creek Watershed

3.4 Manure/Litter/Fertilizer Applications

Farming practices are a source of nutrient contributions to the stream. Organic manure and litter and inorganic fertilizer are applied to croplands. When they are applied in excess or just before a rain event, nutrients can be washed into aquatic ecosystems. For the purposes of developing a value for the potential source of nutrients from fertilizer application to croplands, we assumed one application rate for the whole watershed. Based on local information, the estimated amount of N-fertilizer applied to the cropland is 125 lbs/acre/year. Manure has been applied for about 49 acres of cropland based on CAFO inspection. The chicken manure application rate is based on approximately 2 tons/acre/year.

3.5 Other Sources

Inputs from groundwater are another source of nutrients to Gargathy Creek. Specific values are not available; however, a study in Cherrystone Inlet and other locations on the Eastern Shore provide a TN range of 2.0 - 7.0 mg/l and a TP range of 0.02 - 0.03 mg/l (Reay, 1996).

Atmospheric deposition of air-borne nutrients has been estimated using the value from the literature for the Chesapeake Bay region shown in Table 3.2.

Table 3.2: Nutrient Contribution from Atmospheric Deposition

Nutrient	Loading (lb/acre/year)
TN	11.48
TP	0.71

3.6 Nutrient and BOD/Carbon Loads Summary

As building blocks for biotic production, N, P, and C are utilized in the process of algal growth, and then become available again as the algae die and decay. The natural processes of biotic decay result in the consumption of oxygen. However, excessive levels of decaying material will result in unacceptably low levels of DO. Nitrogen and phosphorus backgrounds, or natural levels, can vary depending upon the location, hydrology, and geology of the watershed. The critical determination in identifying the necessity and amount of nutrient reductions is defining the relationship between the nutrients and the target levels for DO. Quantifying the total loads for nutrients is necessary to understand the effects of various nutrient loads on DO. They are also needed to develop scenarios to model reductions in nutrient inputs to analyze the effect of the reduction on DO. The goal is to identify the nutrient loads that result in ambient concentrations that support the DO target.

The nutrient loads contributed from livestock and wildlife were estimated based on nutrient productions per animal per day. The production rates for livestock were based on data compiled by the American Society of Agricultural Engineers (ASAE, 1994). For wildlife, the nutrient production rates were estimated based on the animal rates that have similar sizes. The contributions from failure of septic systems were estimated based on nutrient concentrations and typical septic overcharge flow rate per person. A value of 70 gal/day/person was assumed and the concentrations for TN, TP, and BOD were 60, 23.5, and 240 mg/l, respectively.

For OC, which is both naturally produced on land and a potential pollutant in the waterway, the accumulation rates were estimated based on empirical information (Cerco and Noel, 2004) and the ratio of C/N obtained from monitoring data during wet-dry seasonal sampling instead of directly surveyed field data. The ratio of TC/TN of the wet-dry seasonal measurement in Onancock Creek, a watershed with similar hydrology and land use features, is from 3 to 7 (Shen *et al*., 2008). Due to the absence of subsurface water quality measurements, pollutant concentrations for interflow and groundwater were derived from the reference data of Cherrystone Inlet (Reay, 1996). The total loads for TN, TP, and OC were estimated based on land use distribution. Load contributions from manure/litter/fertilizer applications were applied to agricultural land uses, those from atmospheric deposition were distributed to all landuse categories, those from wildlife were distributed to all landuses except urban, and those from failure of septic systems were applied to low-intensity residential landuses.

4.0 TMDL DEVELOPMENT

4.1 Overview

A TMDL is the total amount of a pollutant that a waterbody can receive and still meet WQSs. A TMDL may be expressed as a "mass per unit time, toxicity, or other appropriate measure" (CFR, 2006b). These loads are based on an averaging period that is defined by the specific WQSs. A TMDL is the sum of individual wasteload allocations (WLAs) for point sources and load allocations (LAs) for nonpoint sources, incorporating natural background levels. The TMDL must, either implicitly or explicitly, include a margin of safety (MOS) that accounts for the uncertainty in the relationship between pollutant loads and the quality of the receiving waterbody, and in the scientific and technical understanding of water quality in natural systems. In addition, when applicable, the TMDL may include a future allocation (FA) when necessary. This definition is denoted by the following equation:

$$\text{TMDL} = \text{WLAs} + \text{LAs} + \text{MOS} + (\text{FA, where applicable})$$

This section documents the detailed DO and *enterococci* TMDLs and LA development for riverine portion of the Gargathy Creek.

4.2 Selection of a TMDL Endpoint

An important step in developing a TMDL is the establishment of in-stream numerical endpoints, which are used to evaluate the attainment of acceptable water quality and allowable loading capacity. According to WQS 9VAC25-260-50, the numerical criteria for DO for Class II waters are a minimum of 4.0 mg/l and a daily average of 5.0 mg/l. Based on data analysis and field surveys, as well as model sensitivity tests, it is evident that high temperature and low re-aeration, together with the high SOD resulting from the accumulation of organic matter, are the dominant causes of low DO. Reducing nutrients and OC discharge to the Creek will improve the DO condition.

The numerical criteria for enterococci for the recreational use of Gargathy Creek is a *Geometric Mean* of 126 CFU/100mL and a *Single Sample Maximum* of 235 CFU/100ml. The criteria of a Single Sample Maximum of 235 CFU/100ml is more stringent and was set as the TMDL Endpoint.

Because watershed bacteria loadings were computed based on fecal coliform loading using EPA's loading estimation tool, the following translator equation (VA-DEQ, 2003; 2008) was used to convert fecal coliform concentrations to *E. coli*:

$$\log_2(E.coli) = 0.91905 \times \log_2(Fecal\ Coliform) - 0.0172$$

The loading of *E. coli* was obtained based on simulated concentration and flow from the watershed.

4.3 Model Development for Computing TMDL

Numerical models are a widely used approach for TMDL and other water quality studies. In this study, a system of numerical models was applied to simulate the loadings of organic matter and nutrients from the watershed, and the resulting response of in-stream water quality variables such as DO, algae, and nutrients. The modeling system consists of two individual model components: the watershed model and the hydrodynamic-water quality model. The watershed model Loading Simulation Program in C^{++} (LSPC), developed by the USEPA (Shen *et al.*, 2005), was selected to simulate the watershed hydrology and nutrient loads to the Gargathy Creek. Figure 4.1 shows a diagram of the modeling system. The Environmental Fluid Dynamics Computer Code (EFDC) (Park *et al.*, 1995) and recommend by EPA was used to simulate the water quality of the receiving water. A detailed model description, model setup, model calibration, and scenario runs are presented in Appendix A.

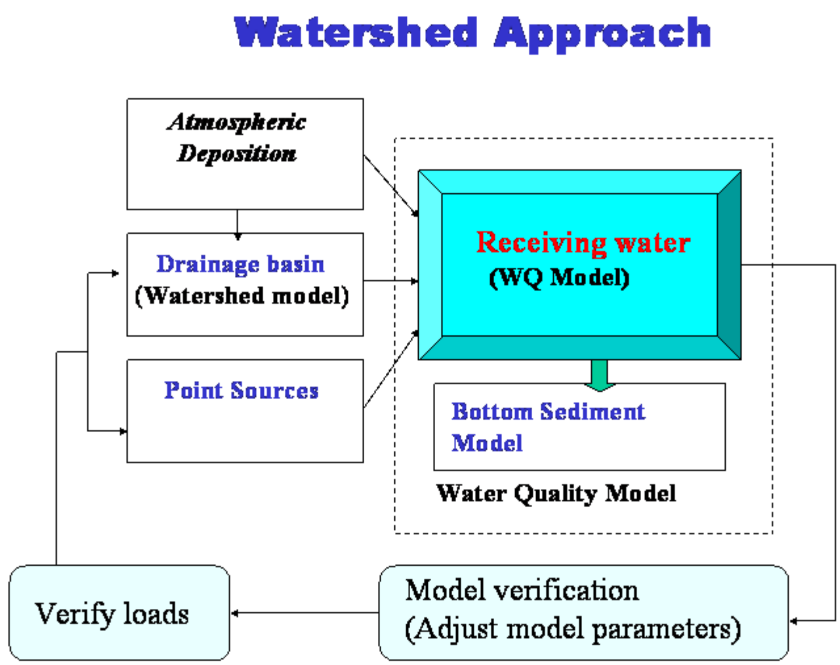


Figure 4.1: Diagram of the Structure of Modeling System

The LSPC model is driven by hourly precipitation and was used to simulate the freshwater flow and its associated nonpoint source pollutants. The simulated freshwater flow and pollutant (nitrogen, phosphorus, and OC) loadings from each sub-watershed were fed into the adjacent water quality model segments. The EFDC model simulates the transport of pollutants and eutrophication processes in the Creek. In order to predict primary production and DO, a large suite of model state variables controlling nutrient and DO dynamics were simulated in the model, including:

1. Algae (green)
2. OC (particulates and dissolved)
3. Organic phosphorus (particulates and dissolved)
4. Phosphate
5. Organic nitrogen (particulates and dissolved)
6. Inorganic nitrogen (ammonium and nitrate)
7. DO

The water column processes are coupled to the sediment diagenesis, which is a group of chemical processes in sediment causing mineralization of organic matters after they have been deposited. The sediment diagenesis model simulates the changes of particulate organic matter deposited from the overlying water column and the resulting fluxes of inorganic substances (ammonium, nitrate, phosphate, and sulfite), and the SOD back to the water column.

The flow simulated by the watershed model was calibrated using USGS gauging data at Gage 01484800 in Guy Creek near Nassawadox, VA, located approximately 43 km south of the Gargathy Creek watershed, which is the only station located along the Eastern Shore. An example of model calibration of the flow is shown in Figure 4.2. Detailed modeling processes and calibration procedure are presented in Appendix A.

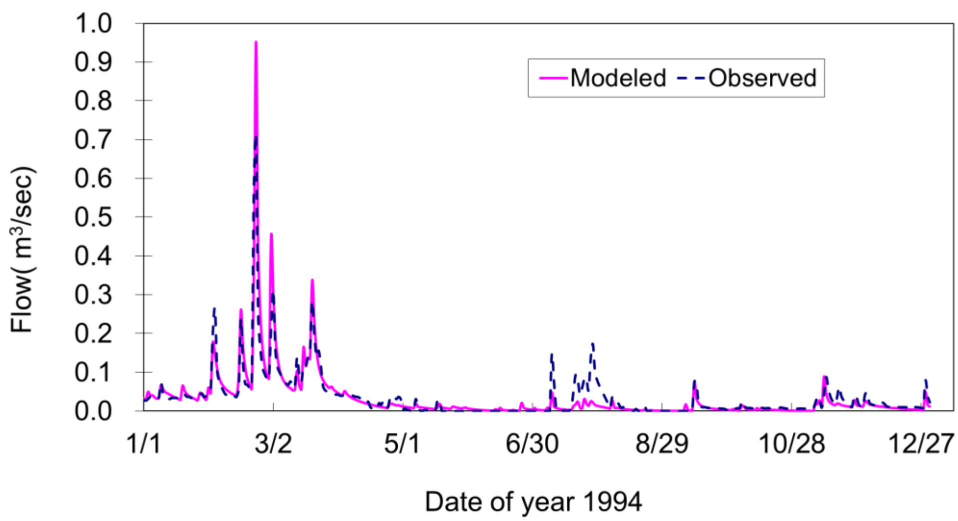


Figure 4.2: Time Series Comparison of Daily Stream Flow between Model Simulation and Observations from USGS Stream Gage 01484800 in 1993

Because the nutrient observation data in the watershed were not available, a linked watershed-in stream model approach was used for the model calibration based on the observations in the receiving water. The water quality model was calibrated in Gargathy Creek using the observation data collected in the Creek for a 10-year simulation period (1996-2005). The selection of this period was due to the precipitation data availability and occurrence of low DO measurements. The model was calibrated based on algae (chl a), TN and TP, phosphate, ammonium, nitrate, Total Kjeldahl nitrogen (TKN), and DO. The computed average nitrogen and phosphorus loadings are 52,602 and 2,765 lb per year, respectively. A comparison of model results against observations for DO and phytoplankton from 1996 to 2005 is shown in Figure 4.3. It can be seen that the model simulated the seasonal DO and algae variation and low DO during this period well. The detailed model setup and calibration processes are presented in Appendix A.

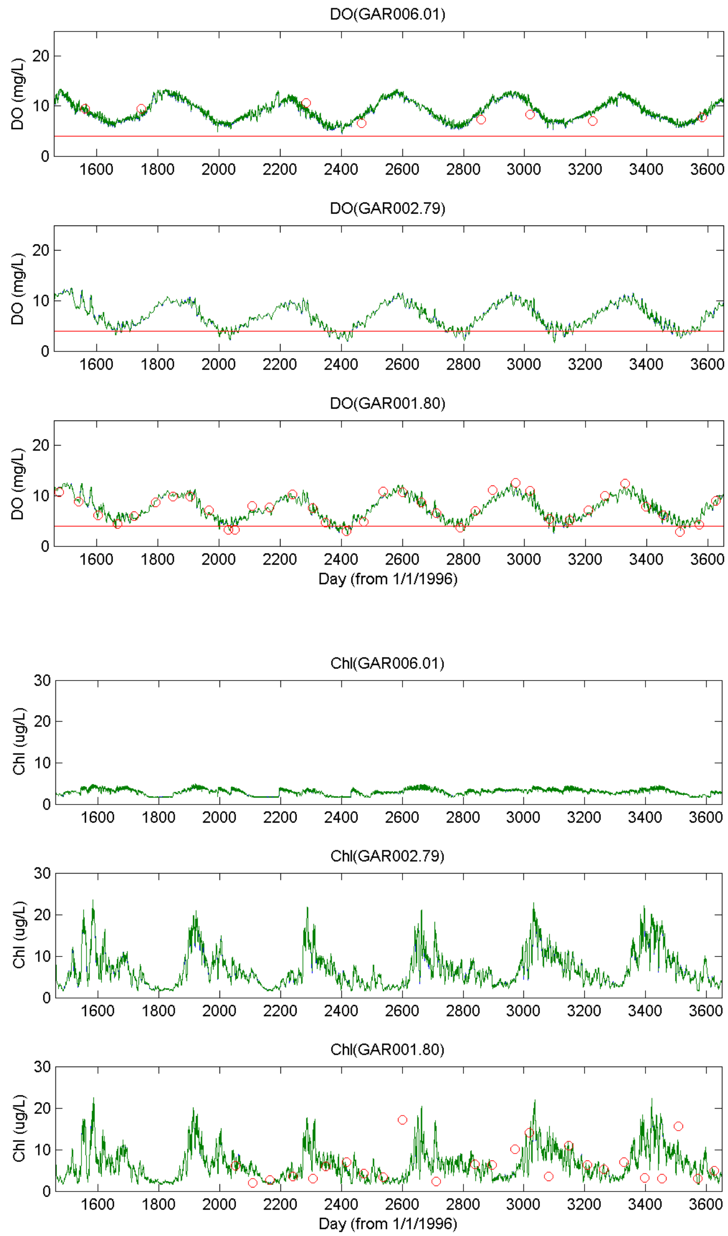


Figure 4.3: Time Series Comparison of DO and Chl a between Model Simulation and Observation from 1996 to 2005

The pathogen loadings input to the landuses were based on the source assessment. Various sources of bacteria were considered, including manure application, wildlife, livestock, pets, and human impact. The loads deposited on land surface and contributed to run-off can be quantified by build-up and wash-off rates. Daily watershed run-off was discharged to the surface of the Gargathy Creek from adjacent watersheds and small creeks connected to it. Because bacteria observations were conducted inside the Creek, a linked watershed-receiving water model approach was conducted for the model simulation based on the observations in the Creek. Model simulation for *E. coli* was conducted for the period of 1996-2005. Model results are shown in Figure 4.4. It can be seen that the model simulates bacteria variations over a ten-year period, indicating that the model is capable of TMDL development. Detailed model calibration and TMDL development are presented in Appendix A.

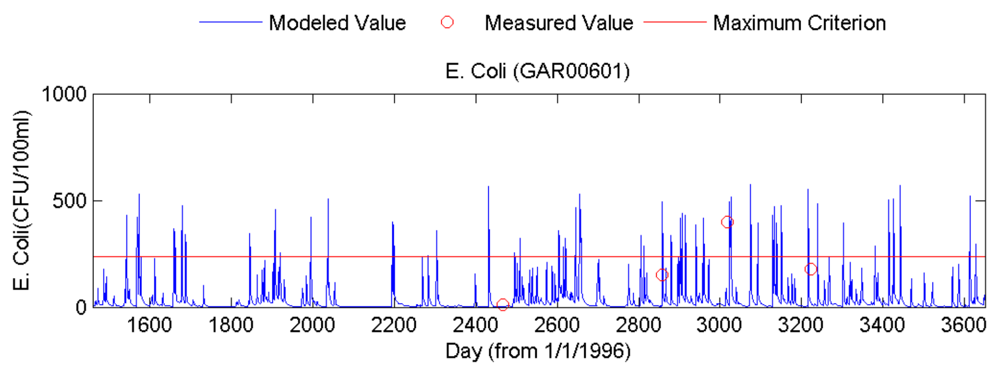


Figure 4.4: Time Series Comparison of Enterococci between Model Simulation and Observation from 1996 to 2005

4.4 Consideration of Critical Conditions and Seasonal Variation

EPA regulations at 40 CFR 130.7 (c)(1) require TMDL studies to take into account critical conditions for stream flow, loading, and water quality parameters. The intent of this requirement is to ensure that the water quality of the waterbody is protected during times when they are most vulnerable. Critical conditions are important because they describe the factors that combine to cause a violation of WQSs and help to identify the actions that may have to be undertaken to meet WQSs.

The current loadings to the waterbody were determined using a long-term record of water quality monitoring (observation) data. The period of record for the data was 1996 to 2011, which spans different flow regimes and temperatures. A ten-year model simulation (1996-2005) was conducted. The selection of the period represents the occurrence of the lowest DO and highest concentration of *enterococci* during the monitoring period. The model was calibrated based on multiple water quality parameters including TN and TP, phosphate, ammonium, nitrate, algae, ON, and DO for eutrophication model and *enterococci* for pathogen transport model. The resulting estimate is quite robust. Seasonal variations involved changes in surface runoff, stream flow, and water quality as a result of hydrologic and climatologic patterns. These are accounted for by the use of this long-term simulation to estimate the current load and reduction targets.

4.5 Margin of Safety

To allocate loads while protecting the aquatic environment, a MOS needs to be considered. A MOS is typically expressed either as unallocated assimilative capacity or as conservative analytical assumptions used in establishing the TMDL (e.g., derivation of numeric targets, modeling assumptions or effectiveness of proposed controls). In the TMDL calculation, the MOS can either be explicitly stated as an additional separate quantity, or implicitly stated, as in conservative assumptions. For Gargathy Creek and UTGC, an explicit MOS of 5% was included in the TMDLs.

4.6 TMDL Computation

According to the endpoints for DO and *enterococci* for the established pollutant reduction target, the allowable nitrogen to meet the DO standards, and *enterococci* loading reduction to meet *enterococci* criteria can be computed.

The load reduction needed for the attainment of the criteria was determined as follows:

$$\textbf{Load Reduction} = \frac{\textbf{Current Load} - \textbf{Allowable Load}}{\textbf{Current Load}} \times 100\%$$

The calculated results for TN and *enterococci* are listed in Tables 4.1 and 4.2, respectively.

Table 4.1: Estimated Loads and Load Reductions for TN and OC

Pollutant	Current Load (lb/day)	Allowable Load (lb/day)	Required Reduction (%)
TN	144.1	95.1	34

Table 4.2: Estimated Loads and Load Reductions for Enterococci

Pollutant	Criterion (cfu/100ml)	Current Load (cfu/day)	Allowable Load (cfu/day)	Required Reduction (%)
E. coli	235	4.50×10^{10}	1.80×10^{10}	60

The loadings for each bacterial source were determined based on source assessment (Appendix B). Load allocation was determined by multiplying the total current and allowable loads by the representative percentage of each source. The percent reduction needed to attain the water quality criterion was allocated to each source category. The results are presented in Table 4.3. The TMDL seeks to eliminate 100% of the human derived fecal component regardless of the allowable load determined through the LA process. Human derived fecal coliforms are a serious concern in the estuarine environment and discharge of human waste is precluded by state and federal law. According to the preceding analysis, reduction of the controllable loads, human, livestock and pets, will not result in achievement of the water quality standard. Absent any other sources, the reduction is allocated to wildlife. The allocations presented demonstrate how the TMDLs could be implemented to achieve water quality standards; however, the state reserves the right to allocate differently, as long as consistency with the achievement of water quality standards is maintained.

Table 4.3: Load Allocation and Required Reduction for Enterococci for Each Source Category

Category	Source Allocation	Current Load (Counts/Day)	Load Allocation (Counts/Day)	Required Reduction
Livestock	58.98%	2.65E+10	2.30E+08	99.14
Wildlife	39.49%	1.78E+10	1.78E+10	0.00
Human	0.01%	4.50E+06	0	100.00
Pets	1.51%	6.80E+08	0	100.00
Total	100.00%	4.50E+10	1.80E+10	60.00

4.7 Summary of TMDL and Load Allocation

There are no industrial or wastewater treatment facilities in the watershed of Gargathy Creek. The loads were allocated to the LA. The TMDLs are summarized as follows:

Table 4.4: Nutrient TMDL (lb/day)

Nutrient	TMDL	=	LA	+	WLA	+	FA	+	MOS
TN	95.1	=	90.4	+	N/A	+	N/A	+	4.7

Table 4.5: Pathogens TMDL (count/day)

Nutrient	TMDL	=	LA	+	WLA	+	FA	+	MOS
E. coli	1.80×10^{10}	=	1.69×10^{10}	+	N/A	+	1.8×10^{8}	+	9.0×10^{8}

Where:

TMDL = Total Maximum Daily Load
LA = Load Allocation (Nonpoint Sources)
WLA = Wasteload Allocation (Point Sources)
FA = Future Allocation (1% of the TMDL)
MOS = Margin of Safety

5.0 IMPLEMENTATION AND PUBLIC PARTICIPATION

5.1 General

Once a TMDL has been approved by the EPA, measures must be taken to reduce pollution levels from both point and nonpoint sources in the stream. For point sources, all new or revised Virginia Pollutant Discharge Elimination System (VPDES)/National Pollutant Discharge Elimination System (NPDES) permits must be consistent with the TMDL WLA pursuant to 40 CFR '122.44 (d)(1)(vii)(B) and must be submitted to EPA for approval. The measures for nonpoint source reductions, which can include the use of better treatment technology and the installation of best management practices (BMPs), are implemented in an iterative process that is described along with specific BMPs in the implementation plan. The process for developing an implementation plan has been described in the "TMDL Implementation Plan Guidance Manual", published in July 2003 and available upon request from the DEQ and DCR TMDL project staff or at http://www.deq.virginia.gov/tmdl/implans/ipguide.pdf. With successful completion of implementation plans, local stakeholders will have a blueprint to restore impaired waters and enhance the value of their land and water resources. Additionally, development of an approved implementation plan may enhance opportunities for obtaining financial and technical assistance during implementation.

5.2 Staged Implementation

In general, Virginia intends for the required nutrient reductions to be implemented in an iterative process that first addresses those sources with the largest impact on water quality. For example, in agricultural areas of the watershed, BMP technology can be used to reduce the runoff of nutrient discharging to the Creek.

Additionally, in both urban and rural areas, reducing the human loading from failing septic systems should be a primary implementation focus because of its health implications. This component could be implemented through education on septic tank pump-outs as well as a septic system repair/replacement program and the use of alternative waste treatment systems.

The iterative implementation of BMPs in the watershed has several benefits:

1. To enable tracking of water quality improvements following BMP implementation through follow-up stream monitoring;
2. To provide a measure of quality control, given the uncertainties inherent in computer simulation modeling;
3. To provide a mechanism for developing public support through periodic updates on BMP implementation and water quality improvements;
4. To help to ensure that the most cost-effective practices are implemented first; and
5. To allow for the evaluation of the adequacy of the TMDL in achieving WQSs.

Watershed stakeholders will have the opportunity to participate in the development of the TMDL implementation plan.

5.3 Reasonable Assurance for Implementation

5.3.1 Follow-Up Monitoring

Following the development of the TMDL, DEQ will make every effort to continue to monitor the impaired stream in accordance with its ambient monitoring program. DEQ's Ambient Watershed Monitoring Plan for conventional pollutants calls for watershed monitoring to take place on a rotating basis, bi-monthly for two consecutive years of a six-year cycle. In accordance with DEQ Guidance Memo No. 03-2004, during periods of reduced resources, monitoring can temporarily discontinue until the TMDL staff determines that implementation measures to address the source(s) of impairments are being installed. Monitoring can resume at the start of the following fiscal year, next scheduled monitoring station rotation, or where deemed necessary by the regional office or TMDL staff, as a new special study.

The purpose, location, parameters, frequency, and duration of the monitoring will be determined by the DEQ staff, in cooperation with DCR staff, the Implementation Plan Steering Committee, and local stakeholders. Whenever possible, the location of the follow-up monitoring station(s) will be the same as the listing station. At a minimum, the monitoring station must be representative of the original impaired segment. The details of the follow-up monitoring will be outlined in the Annual Water Monitoring Plan prepared by each DEQ Regional Office. Other agency personnel, watershed stakeholders, etc. may provide input on the Annual Water Monitoring Plan. These recommendations must be made to the DEQ regional TMDL coordinator by September 30 of each year.

DEQ staff, in cooperation with DCR staff, the Implementation Plan Steering Committee and local stakeholders, will continue to use data from the ambient monitoring stations to evaluate reductions in pollutants ("water quality milestones" as established in the IP), the effectiveness of the TMDL in attaining and maintaining WQSs, and the success of implementation efforts. Recommendations may then be made, when necessary, to target implementation efforts in specific areas and continue or discontinue monitoring at follow-up stations.

In some cases, watersheds will require monitoring above and beyond what is included in DEQ's standard monitoring plan. Ancillary monitoring by citizens', watershed groups, local government, or universities is an option that may be used in such cases. An effort should be made to ensure that ancillary monitoring follows established quality assurance/quality control (QA/QC) guidelines in order to maximize compatibility with DEQ monitoring data. In instances where citizens' monitoring data is not available and additional monitoring is needed to assess the effectiveness of targeting efforts, TMDL staff may request of the monitoring managers in each regional office an increase in the number of stations or that they monitor existing stations at a higher frequency in the watershed. The additional monitoring beyond the original bi-monthly single station monitoring will be contingent on staff resources and available laboratory budget. More information on citizen monitoring in Virginia and QA/QC guidelines is available at http://www.deq.virginia.gov/cmonitor/.

To demonstrate that the watershed is meeting WQSs in watersheds where corrective actions have taken place (whether or not a TMDL or TMDL Implementation Plan has been completed), DEQ must meet the minimum data requirements from the original listing station or a station representative of the originally listed segment. The minimum data requirement for conventional pollutants (bacteria, DO, etc.) is bi-monthly monitoring for two consecutive years. For biological monitoring, the minimum requirement is two consecutive samples (one in the spring and one in the fall) in a one-year period.

5.3.2 Regulatory Framework

While section 303(d) of the CWA and current EPA regulations do not require the development of TMDL implementation plans as part of the TMDL process, they do require reasonable assurance that the LAs and WLAs can and will be implemented. EPA also requires that all new or revised NPDES permits must be consistent with the TMDL WLA pursuant to 40 CFR §122.44 (d)(1)(vii)(B). All such permits should be submitted to EPA for review.

Additionally, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (the "Act") directs the State Water Control Board to "develop and implement a plan to achieve fully supporting status for impaired waters" (Section 62.1-44.19.7). The Act also establishes that the implementation plan shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated costs, benefits and environmental impacts of addressing the impairments. EPA outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process." The listed elements include implementation actions/management measures, timelines, legal or regulatory controls, time required to attain WQSs, monitoring plans and milestones for attaining WQSs.

For the implementation of the WLA component of the TMDL, the Commonwealth intends to utilize the VPDES program, which typically includes consideration of the WQMIRA requirements during the permitting process. Requirements of the permit process should not be duplicated in the TMDL process, and with the exception of stormwater-related permits, permitted sources are not usually addressed during the development of a TMDL implementation plan.

For the implementation of the TMDL's LA component, a TMDL implementation plan addressing at a minimum the WQMIRA requirements will be developed. An exception are the municipal separate storm sewer systems (MS4s) which are both covered by NPDES permits and expected to be included in TMDL implementation plans, as described in the stormwater permit section below. Watershed stakeholders will have opportunities to provide input and to participate in the development of the TMDL implementation plan. Regional and local offices of DEQ, DCR, and other cooperating agencies are technical resources to assist in this endeavor.

In response to a Memorandum of Understanding (MOU) between the EPA and DEQ, DEQ also submitted a draft Continuous Planning Process to EPA in which DEQ commits to regularly updating the Water Quality Management Plans (WQMPs). Thus, the WQMPs will be, among other things, the repository for all TMDLs and TMDL implementation plans developed within a river basin.

DEQ staff will present both EPA-approved TMDLs and TMDL implementation plans to the State Water Control Board for inclusion in the appropriate WQMP, in accordance with the CWA's Section 303(e) and Virginia's Public Participation Guidelines for Water Quality Management Planning. DEQ staff will also request that the State Water Control Board (SWCB) adopt TMDL WLAs as part of the Water Quality Management Planning Regulation (9VAC 25-720), except in those cases when permit limitations are equivalent to numeric criteria contained in the Virginia WQSs. This regulatory action is in accordance with §2.2-4006A.4.c and §2.2-4006B of the Code of Virginia. SWCB actions relating to water quality management planning are described in the public participation guidelines referenced above and can be found on DEQ's website under http://www.deq.state.va.us/tmdl/pdf/ppp.pdf

5.3.3 Implementation Funding Sources

Cooperating agencies, organizations and stakeholders must identify potential funding sources available for implementation during the development of the implementation plan in accordance with the "Virginia Guidance Manual for Total Maximum Daily Load Implementation Plans". Potential sources for implementation may include the U.S. Department of Agriculture's Conservation Reserve Enhancement and Environmental Quality Incentive Programs, EPA Section 319 funds, the Virginia State Revolving Loan Program, Virginia Agricultural Best Management Practices Cost-Share Programs, the Virginia Water Quality Improvement Fund, tax credits and landowner contributions.

The TMDL Implementation Plan Guidance Manual contains additional information on funding sources, as well as government agencies that might support implementation efforts and suggestions for integrating TMDL implementation with other watershed planning efforts.

5.4 Public Participation

The development of the TMDL would not have been possible without public participation. The first public meeting was held on March 28, 2012 at Accomack-Northampton Planning District Commission, to inform the stakeholders of TMDL development process and to obtain feedback. Results of the hydrologic calibration, bacteria source estimates, and TMDL development were discussed in the public meeting. The second public meeting was held on July 18, 2012 at the Accomack-Northampton Planning District

Commission. Updated nutrient loading and TMDL results were presented and discussed in the public meeting.

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Appendix A: Model Development

A.1 Model Development for DO

Numerical models are a widely used approach for TMDL and other water quality studies. In this study, a system of numerical models was developed to simulate the loadings of organic matter and nutrients from the watershed, and the resulting response of in-stream water quality variables such as DO, algae, and nutrients. The modeling system consists of two individual model components: the watershed model and the hydrodynamic-water quality model. The watershed model LSPC, developed by the USEPA, was selected to simulate the watershed hydrology and nutrient loads to the receiving waterbodies of Gargathy Creek. The EFDC model (Park *et al*., 1995) was used to simulate the water quality of the receiving water. Figure A-1 shows a diagram of the modeling system.

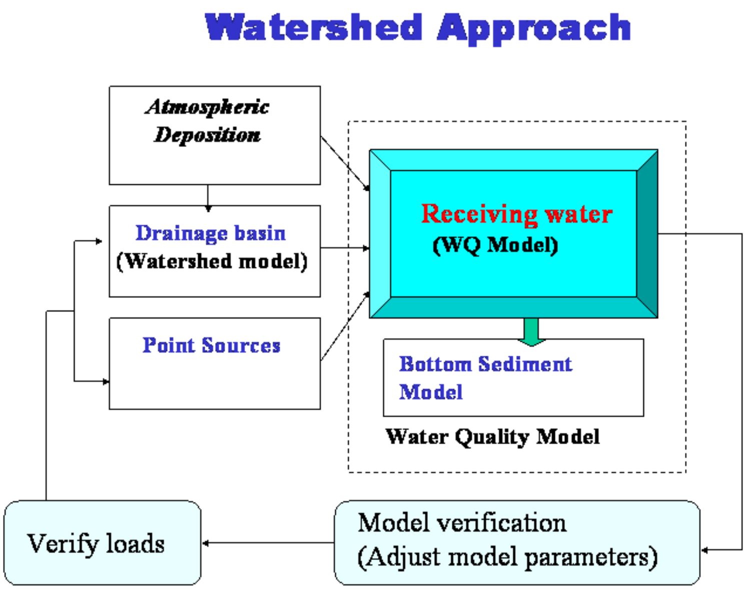


Figure A-1: Diagram of the Structure of Modeling System

A.1.1 Model Description

A.1.1.1 Watershed Model

The LSPC model is a stand-alone, personal computer-based watershed modeling program developed in Microsoft C^{++} (Shen *et al*., 2005). It includes selected Hydrologic Simulation Program FORTRAN (HSPF) algorithms for simulating hydrology, sediment, and general water quality on land, as well as a simplified stream transport model (USEPA, 2004; Shen *et al*., 2002a, b; USEPA, 2001a, b). Like other watershed models, LSPC is a precipitation-driven model and requires necessary meteorological data as model input.

The LSPC model was configured for Gargathy Creek watershed to simulate the watershed as 73 hydrologically connected subwatersheds (Figure A-2). The subwatersheds were used as modeling units for the simulation of flow, nutrient, and pathogen loads based on meteorology, land use, and nutrient application and pathogen deposition on the watershed. LSPC was used to simulate the freshwater flow and its associated nonpoint source pollutants. The simulated freshwater flow and pollutant (nitrogen, phosphorus, OC, etc.) and pathogen loadings for each subwatershed were fed into the adjacent water quality model segments. In simulating nonpoint source pollutants from the watershed, LSPC uses a traditional buildup and washoff approach. Pollutants from various sources (fertilizer, atmospheric deposition, wildlife, septic system etc.) accumulate on the land surface and are available for runoff during rain events. Different land uses are associated with various anthropogenic and natural processes that determine the potential pollutant load. The pollutants contributed by interflow and groundwater are also modeled in LSPC for each land use category. Pollutant loadings from surface runoff, interflow, and groundwater outflow are combined to form the final loading output from LSPC. In summary, nonpoint sources from the watershed are represented in the model as land-based runoff from the land use categories to account for their contribution (USEPA, 2001a).

For this study, the watershed processes were simulated based on buildup and washoff processes. The final loads were converted to model accumulation rates (ACQOP, units of lb/acre/day for nutrients or counts/acre/day for pathogen). The ACQOP can be calculated for each land use based on all sources contributing nutrients to the land surface. For example, croplands receive nutrients from fertilizer and manure application, atmospheric deposition, and feces from wildlife. Summarizing all these sources together can derive the accumulation rates for croplands. These loading parameters were adjusted accordingly during model calibration. The loads discharged to the stream were estimated based on model simulation results (see model simulation section). The other two major parameters governing water quality simulation, the maximum storage limit (SQOLIM, unit in lb/acre/day for nutrients or counts/acre/day) and the washoff rate (WSQOP, unit in inchs/hour), were specified based on soil characteristics and land use practices, and further adjusted during the model calibration. The WSQOP is defined as the rate of surface runoff that results in 90% removal of pollutants in one hour. The lower the value, the more easily washoff occurs.

A.1.1.2 Hydrodynamic Model

Hydrodynamic transport is the essential dynamic for driving the movement of dissolved and particulate substances in aquatic waters. Hydrodynamic models are used to represent transport patterns in complex aquatic systems. For the Gargathy Creek study, the EFDC model was selected to simulate hydrodynamics. The EFDC is a general purpose modeling package for simulating 1-, 2-, and 3-dimensional flow and transport in surface water systems including: rivers, lakes, estuaries, reservoirs, wetlands, and oceanic coastal regions. It was originally developed at the Virginia Institute of Marine Science for estuarine and coastal applications and is considered public domain software (Hamrick, 1992a). The model code has been extensively tested and documented. The EFDC model has been integrated into the EPA's TMDL Modeling Toolbox for supporting TMDL development (http://www.epa.gov/athens/wwqtsc/html/hydrodynamic_models.html).

The EFDC model solves the continuity and momentum equations for surface elevation and horizontal and vertical velocities. The model simulates density and gravitationally induced circulation as well as tidal and wind-driven flows, spatial and temporal distributions of salinity, temperature, and suspended sediment concentration, and conservative tracers. The model uses the efficient numerical solution routines to improve the accuracy and efficiency of the model applications. The model has been applied to a wide range of environmental studies in the Chesapeake Bay system and other systems (e.g., Hamrick *et al.*, 1992b; Shen *et al.*, 1999; Shen and Kuo, 1999).

Inputs to the EFDC model for Gargathy Creek include:

- Bathymetry
- Freshwater inputs (lateral and up-stream) from watersheds
- Surface meteorological parameters (wind, atmospheric pressure, solar radiation, dry and wet temperature, humidity, and cloud cover)
- Nutrient loadings from watershed

The model uses a grid to represent the study area (Figure A-2). The grid is comprised of cells connected through the modeling process. The scale of the grid (cell size) determines the level of resolution in the model and the model efficiency from an operational perspective. The smaller the cell size, the higher the resolution and the lower the computational efficiency. The model grid used for Gargathy Creek was developed based on the high-resolution shoreline digital files from USEPA and USGS topographic maps. The grid covered the entire Creek so that the mouth of the Creek can be used to set the boundary condition. Setting the model boundary well outside the model area of interest increased the model accuracy by reducing the influence of the boundary condition. There were a total of 423 cells in the horizontal, surface grid.

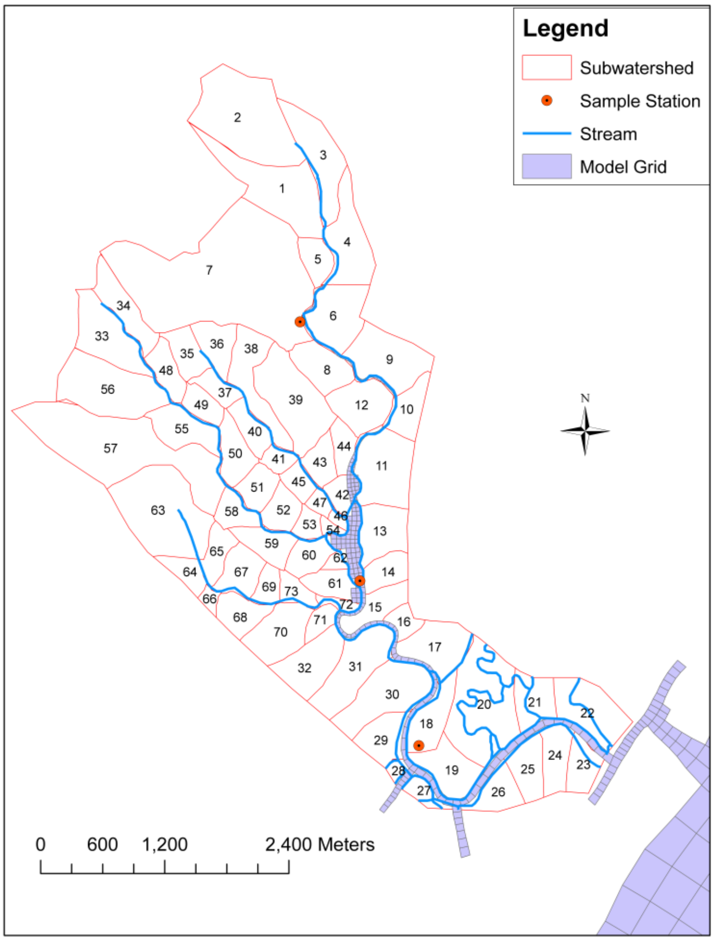


Figure A-2: A Map of Subwatersheds and Model Grid

A.1.1.3 Model Linkage

A linkage between LSPC and EFDC has been developed so that the daily freshwater discharges from the watershed can be directly input into the receiving water model. All of the freshwater discharge or nonpoint source inputs were assigned to specific grid cells.

The EFDC has been integrated with a water column eutrophication component and a sediment diagenesis component (Park *et al*., 1995). The integrated model simulates the spatial and temporal distributions of water quality parameters including DO, algae, and various forms of carbon, nitrogen, phosphorus and silica.

Central to the eutrophication component of the model is the relationship between algal primary production and the concentration of DO. In order to predict primary production and DO, a large suite of model state variables representing nutrient dynamics are simulated in the model (See Table A-1). The eutrophication model has the following water quality variable groups:

- Algae (green, cyanobacteria, and diatoms)
- Macro-algae
- OC (labile and refractory particulates, and dissolved)
- Organic phosphorus (labile and refractory particulates, and dissolved)
- Phosphate
- Organic nitrogen (labile and refractory particulates, and dissolved)
- Inorganic nitrogen (ammonium and nitrate)
- Silica (particulate and bio-available)

The eutrophication processes included in the EFDC were those described by Park *et al*. (1995). A diagram of model state variables and their relationship is demonstrated in Figure A-3. Each state variable is defined in Table A-1.

Table A-1: EFDC Model Water Quality State Variables

Abbreviates	State Variable
Bc	cyanobacteria
Bd	diatom algae
Bg	green algae
Bm	macroalgae
COD	chemical oxygen demand
DO	dissolved oxygen
DOC	dissolved organic carbon
DOP	dissolved organic phosphorus
DON	dissolved organic nitrogen
FC	fecal coliform bacteria
LPOC	labile particulate organic carbon
LPON	labile particulate organic nitrogen
LPOP	labile particulate organic phosphorus
NH_4^+	ammonia nitrogen
NO23	nitrate nitrogen
PO4t = PO4d+ PO4p	total phosphate=dissolved phosphate+ particulate phosphate
RPOC	refractory particulate organic carbon
RPON	refractory particulate organic nitrogen
RPOP	refractory particulate organic phosphorus
Sad	dissolved available silica
Sap	particulate biogenic silica

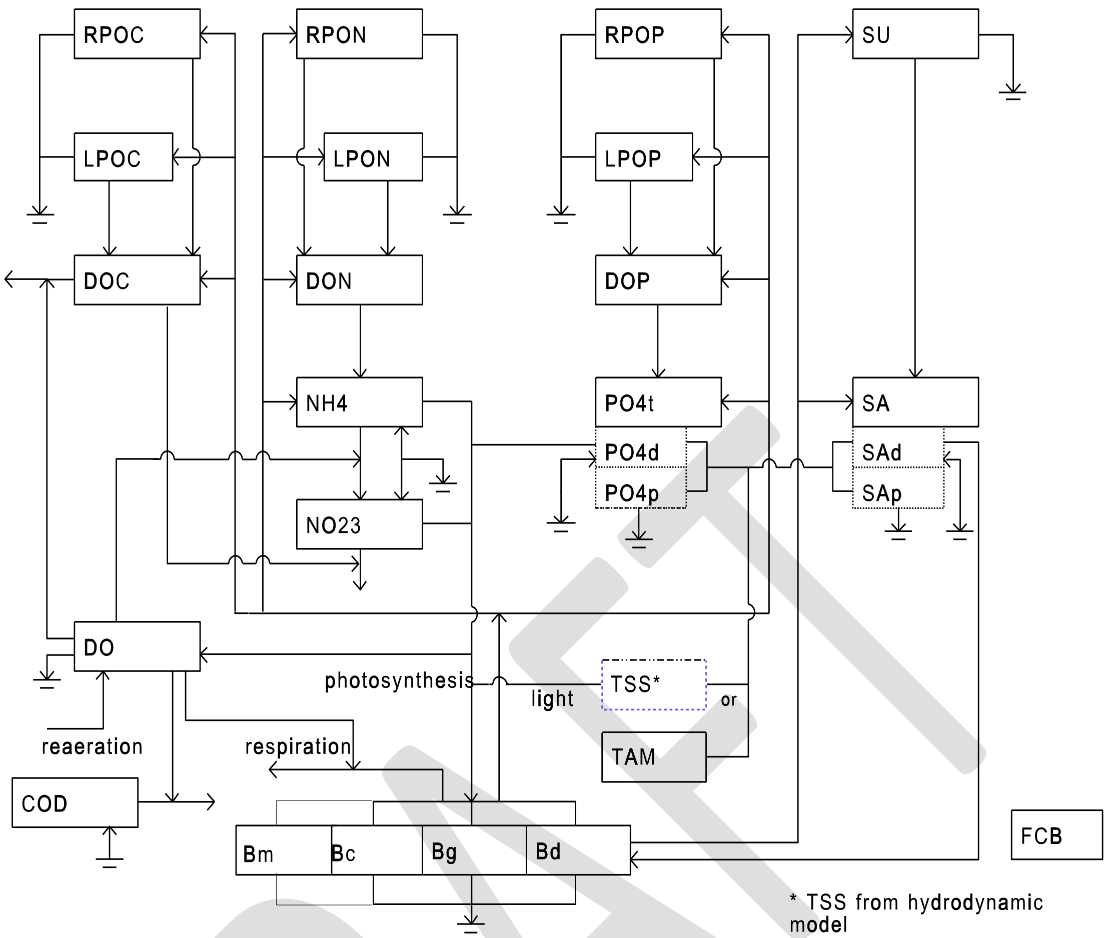


Figure A-3: Diagram of Water Quality Model State Variables and Their Relationship

Sediment diagenesis is a group of chemical processes in sediment causing mineralization of organic matters after they have been deposited. The sediment diagenesis model component simulates the changes of particulate organic matter deposited from the overlying water column and the resulting fluxes of inorganic substances (ammonium, nitrate, phosphate, and silica) and SOD back to the water column. The integration of the sediment processes component with the water quality model not only enhances the model's predictive capability of water quality parameters, but also enables it to simulate the long-term changes in water quality conditions in response to changes in nutrient loadings. A model linkage is shown in Figure A-4.

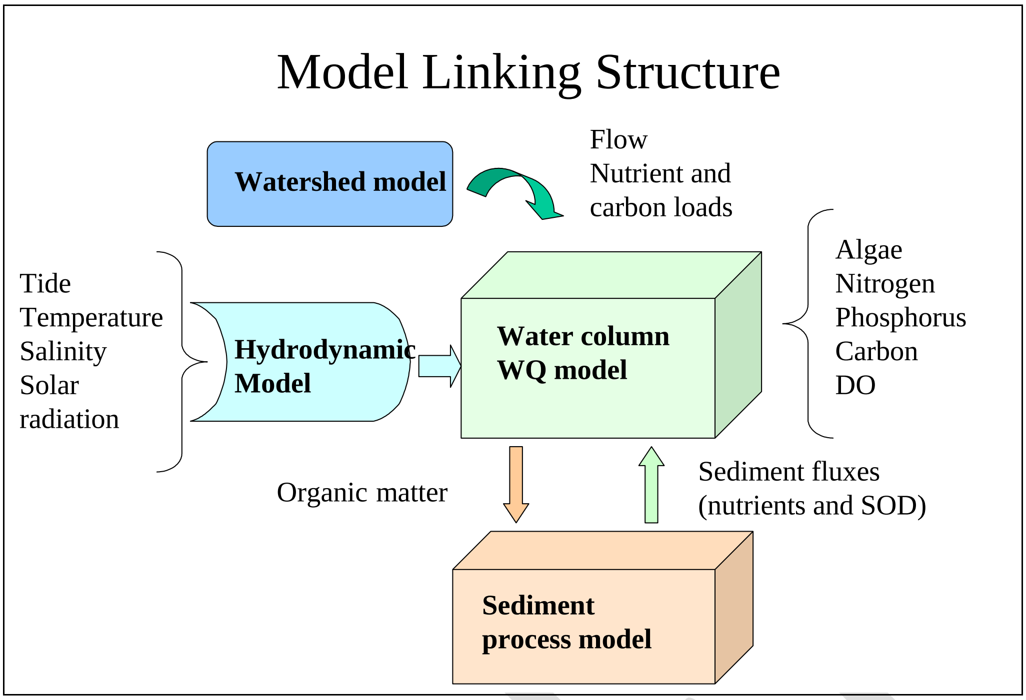
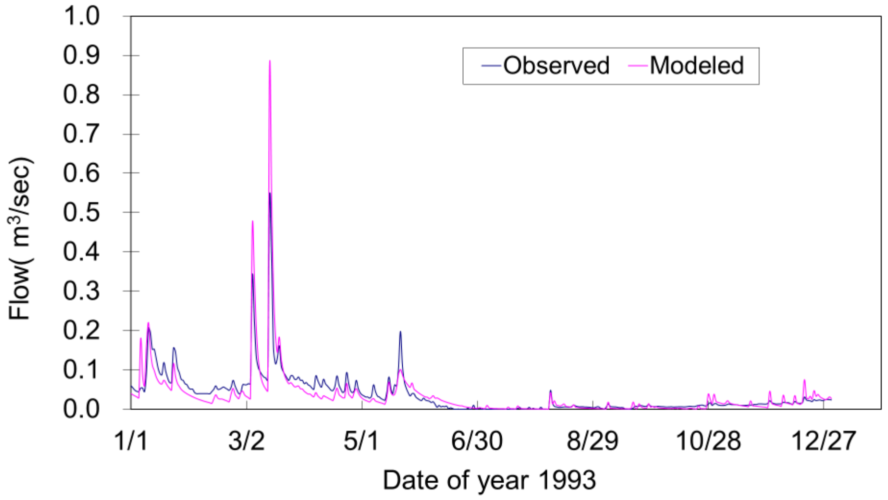


Figure A-4: Diagram of Model Linking Structure

A.1.2 Model Calibration and Verification

A.1.2.1 Watershed Model

The calibration process involved adjustment of the model parameters used to represent the hydrologic processes until acceptable agreement between simulated flows and field measurements were achieved. Since there is no USGS gage or any other continuous flow data available in the Gargathy Creek watershed, a reference watershed was used for calibration. The USGS Gage 01484800 in Guy Creek near Nassawadox, VA, located approximately 34 km south of the Gargathy Creek Watershed, was used to calibrate the model parameters for hydrology simulation. The derived parameters were further verified with local flow data collected by the VADEQ in the Onancock Creek watershed. The Onancock Creek watershed has similar landuse, soil, and characteristics to Gargathy Creek. Figure A-5 shows the time series comparison of daily stream flow for years 1993 and 1994. Figure A-6 shows the 10-year daily stream flow frequency comparison between the model result and field data collected by the USGS gage. Based on the comparison, it can be seen that LSPC has reasonably reproduced the observed flow over a 10-year period.



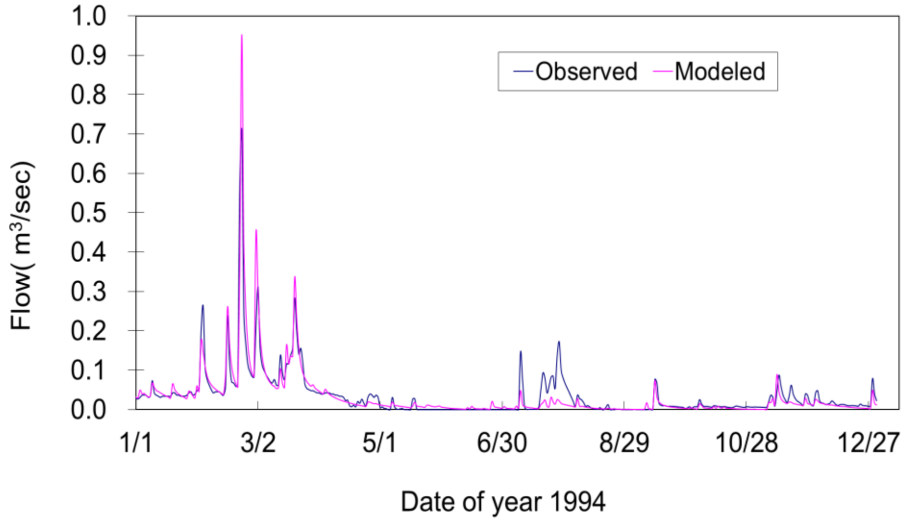


Figure A-5: Time Series Comparison of the Daily Stream Flow between Model Simulation and Observed Data from USGS Stream Gage 01484800 in 1993 and 1994

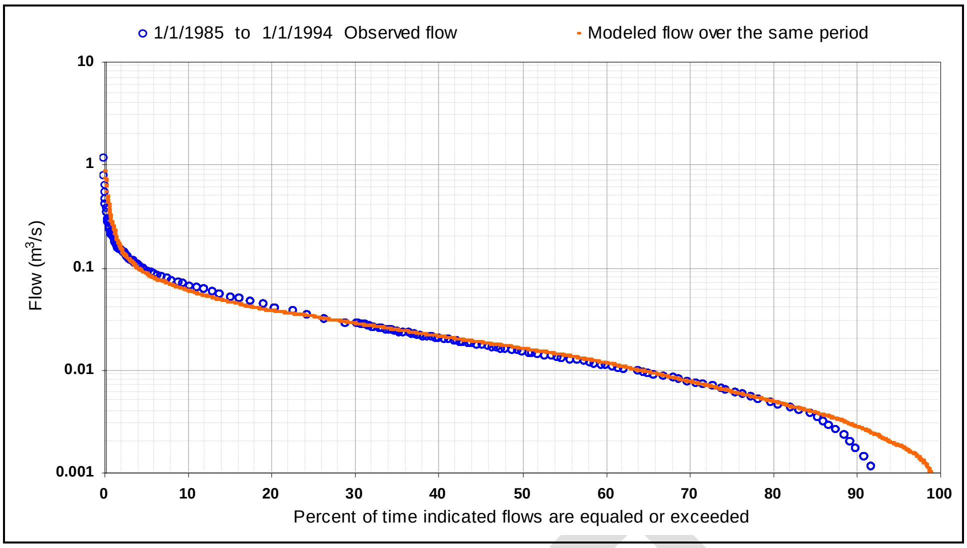


Figure A-6: 10-year Accumulated Daily Stream Flow Comparison between Model Simulation and the Reference Flow Station USGS 01484800

Calibration of water quality simulations are typically performed using water quality measurements from the watershed. Absent the necessary data from Gargathy Creek watershed, the calibration was performed on the observation data in Gargathy Creek using an iterative approach between the watershed model and receiving water model. The watershed model parameters (accumulation and lost rates) for nitrogen and phosphate associated with surface runoff of each land use category were estimated on the basis of all available field survey data using USEPA recommended loading production rates (USEPA, “NutrientTool.xls” program, 1998). For OC, which is both naturally produced on land and a potential pollutant in the waterway, accumulation rates were estimated based on empirical information (Cerco and Noel, 2004) and the ratio of carbon to nitrogen was obtained from monitoring instead of directly surveyed field data in the nearby watershed. The measurement shows the ratio is from 3 to 7. Due to the absence of subsurface water quality measurements in the Creek, pollutant concentrations for interflow and groundwater were derived from reference data from Cherrystone Inlet (Reay, 1996). The initial loading output from LSPC was fed into the receiving water quality model. A ten-year model simulation (1996-2005) was conducted. The selection of this period is due to the availability of precipitation data and low DO occurrence at each station during this period. The comparison of modeled state variables and observations in the receiving water provided a reference for calibration of the watershed model. The pathogen watershed model calibration is identical to nutrient watershed model. The model calibration is based on the transport model and observations in Gargathy Creek. A ten-year model simulation was conducted. The pathogen accumulation and lost rates were adjusted so that the bacteria concentration in the Creek agrees with observations.

A.1.2.2 Receiving Water Model Results

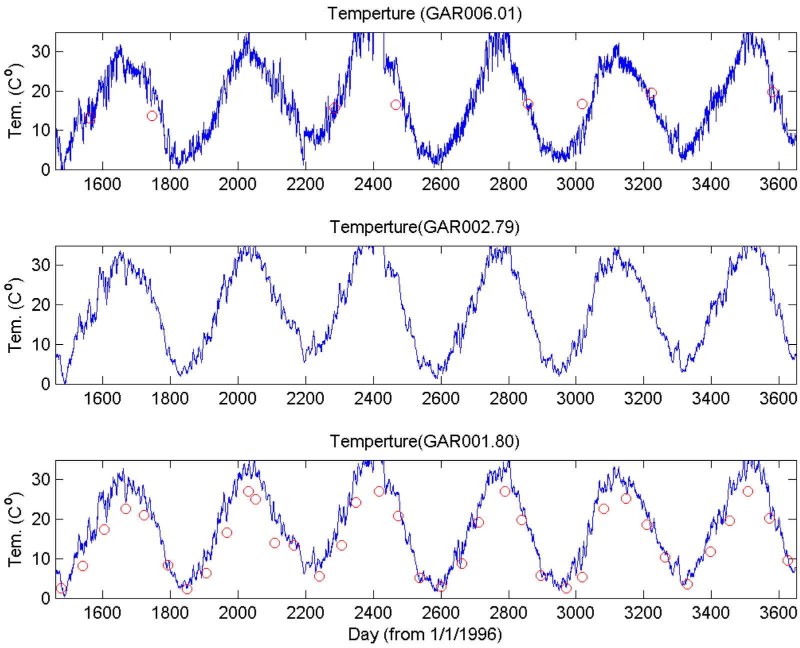
In the EFDC model, the eutrophication component of the receiving water model is coupled to the hydrodynamic model, so that the transport fields simulated by the hydrodynamic model drive the eutrophication component. The eutrophication model simulates dynamics of phytoplankton, DO, nitrogen, phosphorus, and carbon in the water column. The water temperature from the hydrodynamic model is used in the calculation of kinetic processes of the eutrophication model.

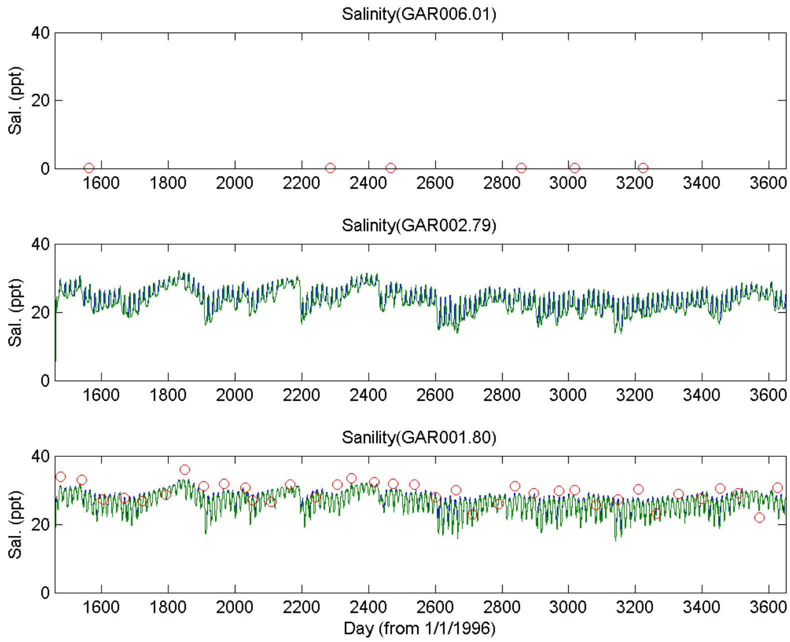
The most important input data for simulation of eutrophication process and DO in the Creek are the nutrient and carbon loads from the watershed delivered via surface runoff or ground water. The watershed model simulated TP, TN, and total carbon. The loading discharge locations were identical to flow discharge locations along the bank of the Creek. The TN, TP, and TC simulated by the watershed model were split into individual state variables for the eutrophication model component. The total organic nitrogen, phosphorus, and carbon were split into refractory, labile, and dissolved nitrogen, phosphorus, and carbon. The ratios used to split the variables were based on Chesapeake Bay modeling and eutrophication model applications in Onancock Creek, and adjusted during the model calibration.

In this study, a typical set of model kinetic parameters was initially used for the model setup. The set of model parameters originated from the Chesapeake Bay eutrophication model (Cerco and Cole, 1994; Park *et. al.*, 1995). Most of these kinetic parameters were used without any modification in this study. A few key model parameters, including growth, respiration, mortality, and settling rates, were further adjusted during the model calibration process. Literature values (Thomann and Mueller, 1987; Johnson *et al.*, 1985) were used as a guideline so that calibrated kinetic parameters were within the accepted ranges.

The sediment diagenesis model (DiToro and Fitzpatrick, 1993) was coupled to the water column eutrophication model component to simulate nutrient exchanges on the water-sediment interface. The model was run iteratively for 3 years with the use of 1996 nutrient loads. The model results at the end of the second year were used as the initial condition for model simulation. It was found that after 3 years of iterative simulation, the water quality concentrations in the sediment bed approached a dynamic equilibrium.

A model calibration and validation time period for the simulation was from 1/1/1996 to 12/31/2005. The selection of this period was due to the availability of precipitation data and lowest DO occurrence during this period. The model calibration was conducted by comparing the model prediction against in-stream monitoring data. The model calibration results are shown from Figure A-7 to Figure A-12. The simulation of pathogen was conducted using the transport model. The daily bacteria loadings were discharged to the creek thorough adjacent watersheds. A constant decay rate of 1/day (Shen and Zhao, 2010) was used for the model simulation of bacteria. Model results are shown in Figure A-13.





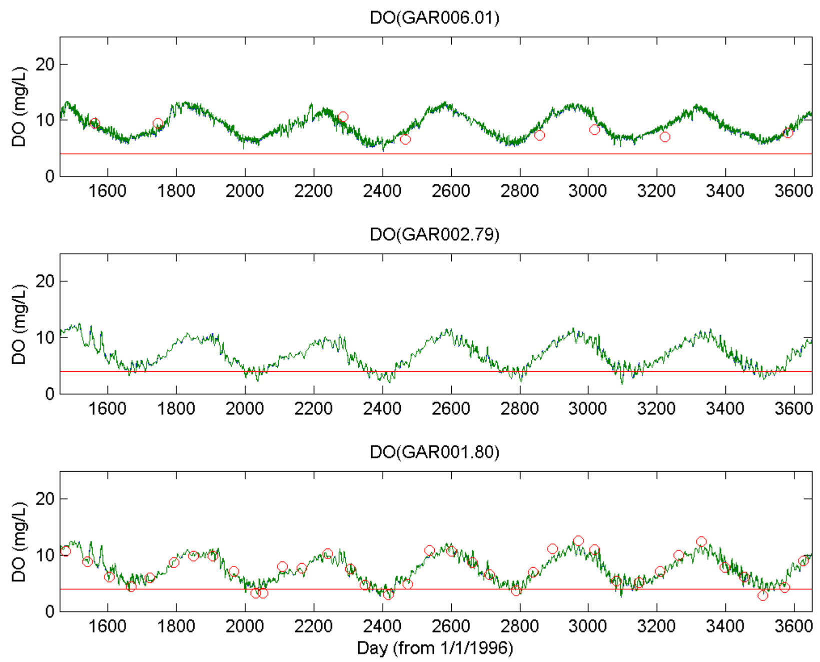


Figure A-7: Comparison of Modeled and Observed Temperature, Salinity, and DO

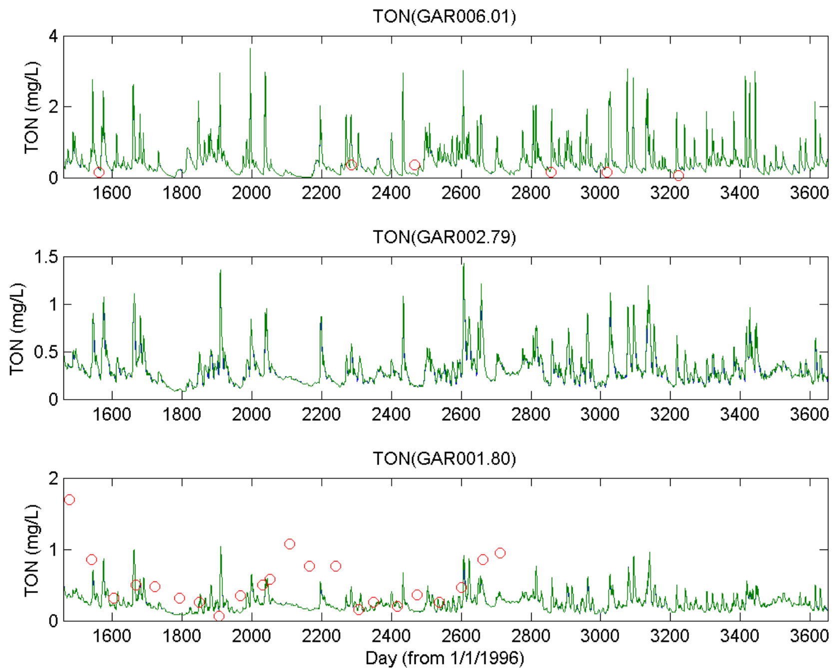


Figure A-8: Comparison of Modeled and Observed TON

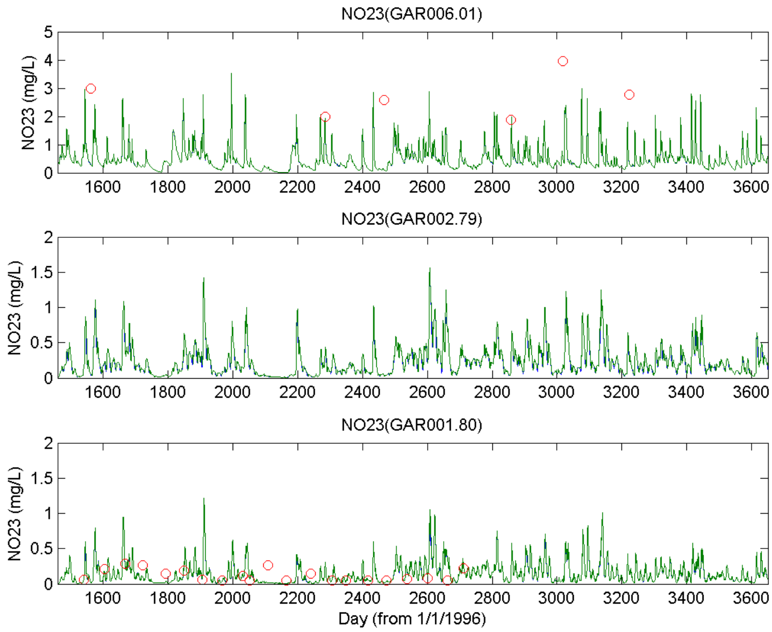


Figure A-9: Comparison of Modeled and Observed NO_{23}

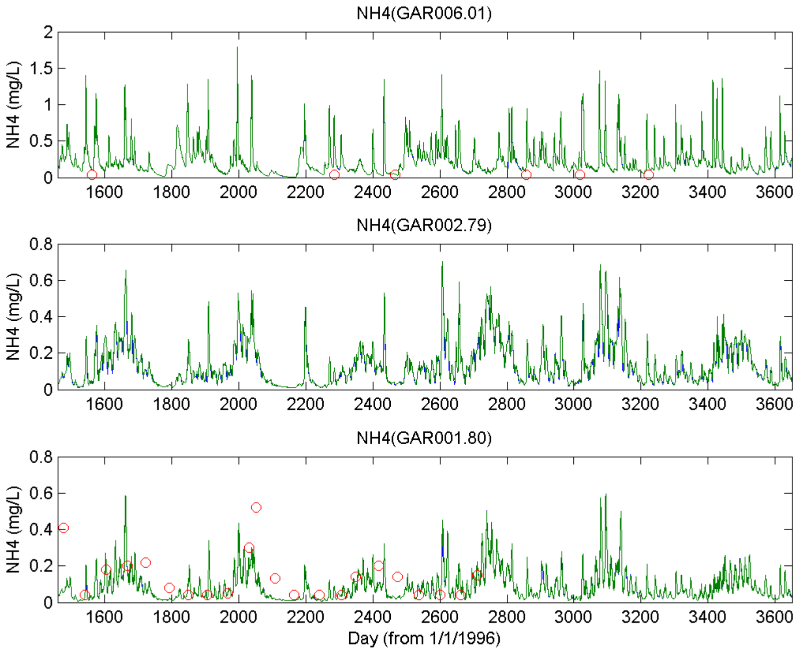


Figure A-10: Comparison of Modeled and Observed NH_4^+

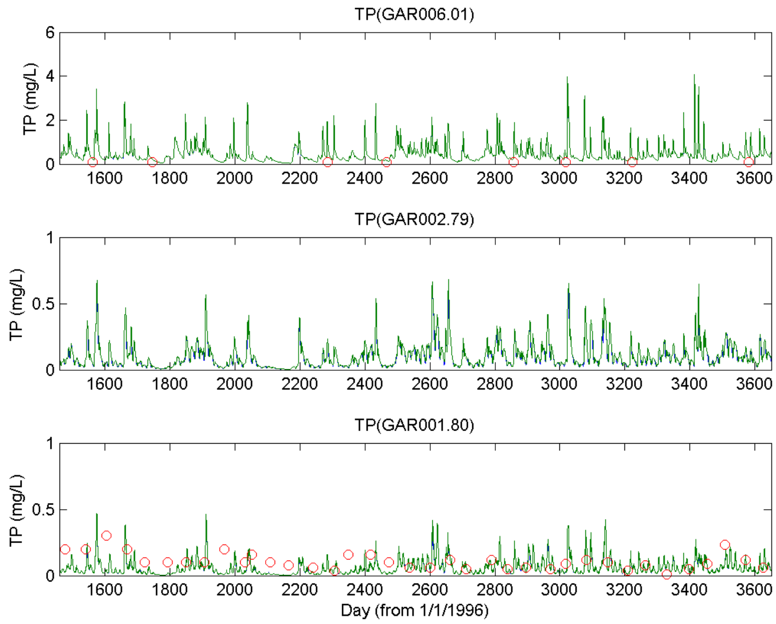


Figure A-11: Comparison of Modeled and Observed TP

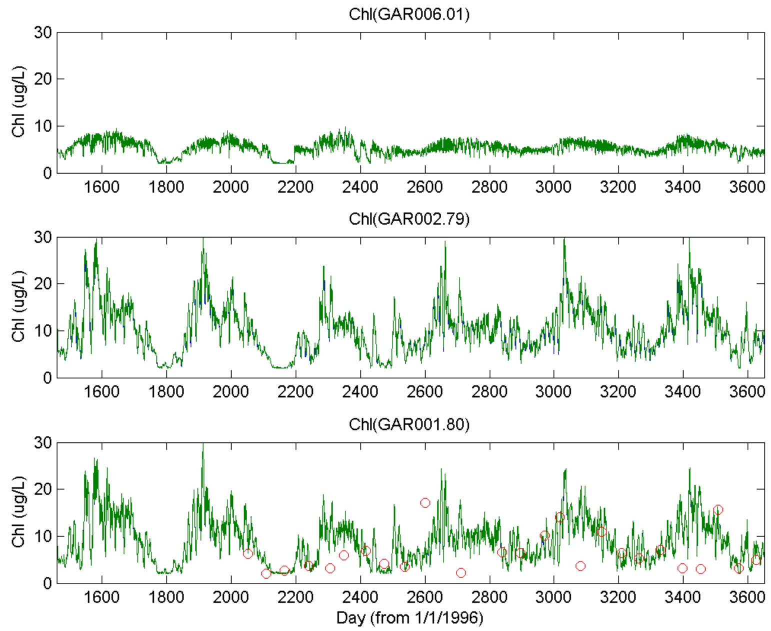


Figure A-12: Comparison of Modeled and Observed Chl a

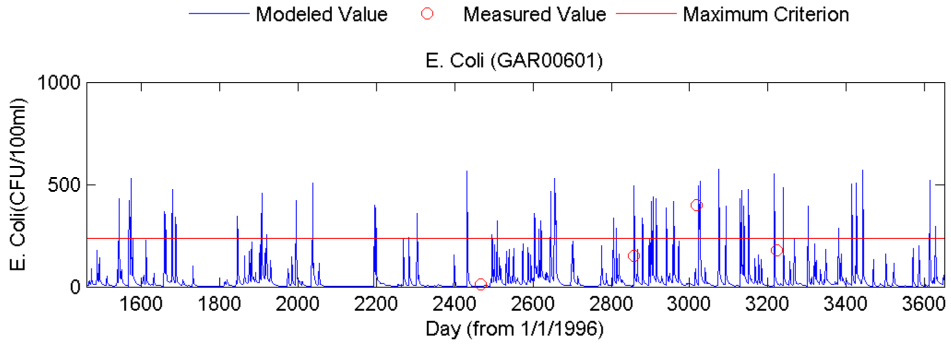


Figure A-13: Comparison of Modeled and Observed E. Coli

A.2 Allocable Load

A.2.1 Current Condition

A ten-year model simulation from 1996 to 2005 was selected to represent the current condition, which was the same period used for the model calibration. The selection of these ten years captured a wet, a mean, and a dry meteorologic condition. The loads of nitrogen, phosphorus, and OC were generated by the LSPC model with calibrated model parameters. The loading and flow output from the watershed model were input to the receiving water model (EFDC) to simulate hydrodynamic and water quality condition in the Creek. Average annual loads were calculated for TN, TP, and OC, respectably. Figure A-14 shows the annual loading distribution. The estimated loads were used to represent the existing condition. The cause of low DO is mainly due to the organic matters deposition resulting in high SOD during the summer and the influences of salt marshes that consume DO (Figure A-15). Simulations over a similar period for pathogens were performed and the averaged loads for a 10-year period were used to represent the current condition, which is $4.50{\times}10^{10}$ counts/year.

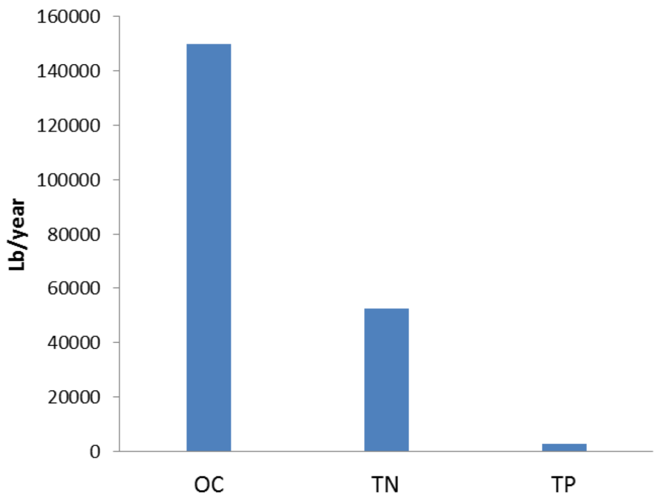


Figure A-14: Estimated Existing Annual Mean Nutrients Loading Discharged to Gargathy Creek

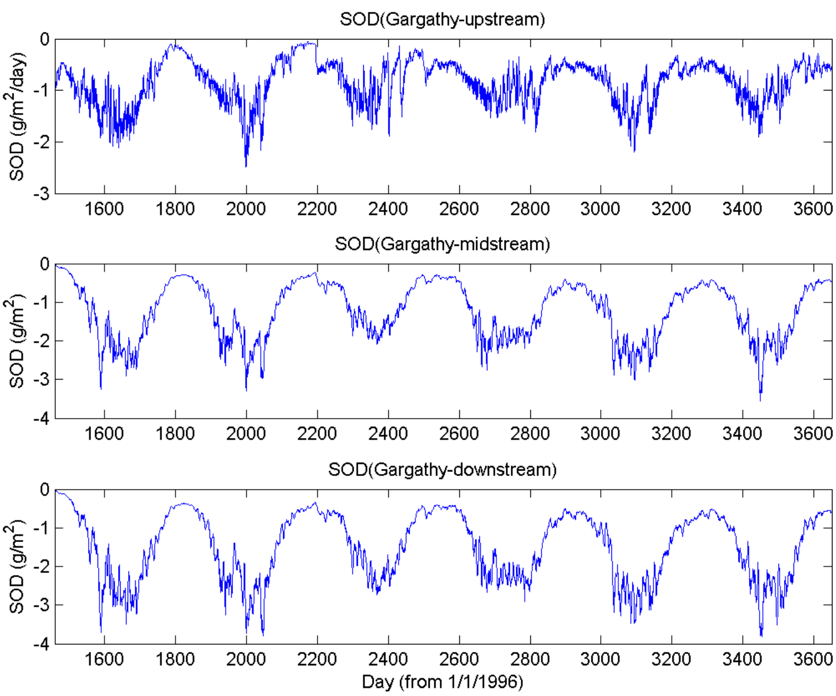


Figure A-15: Simulated SOD in the Gargathy Creek

A.2.2 Allowable Load

According to the DO endpoint, a series of nutrient reduction scenarios were conducted to find the allowable loads to evaluate the attainment of acceptable in-stream water quality. It is noted that only nitrogen and OC load reductions were required for DO to meet the endpoint of instantaneous 4 mg/L. The estimated reduction of nitrogen and OC reductions of 34% are required for DO to meet the water quality standard. With a 34% reduction of TN, the in-stream concentration meets the EPA recommended criteria. The DO distribution is shown in Figures A-16.

According to the *enterococci* endpoint, a series of bacteria load reductions was conducted to find the allowable loads to meet the attainment of enterococci in Gargathy Creek (Figure A-17). The estimated bacteria load reduction is approximately 60%.

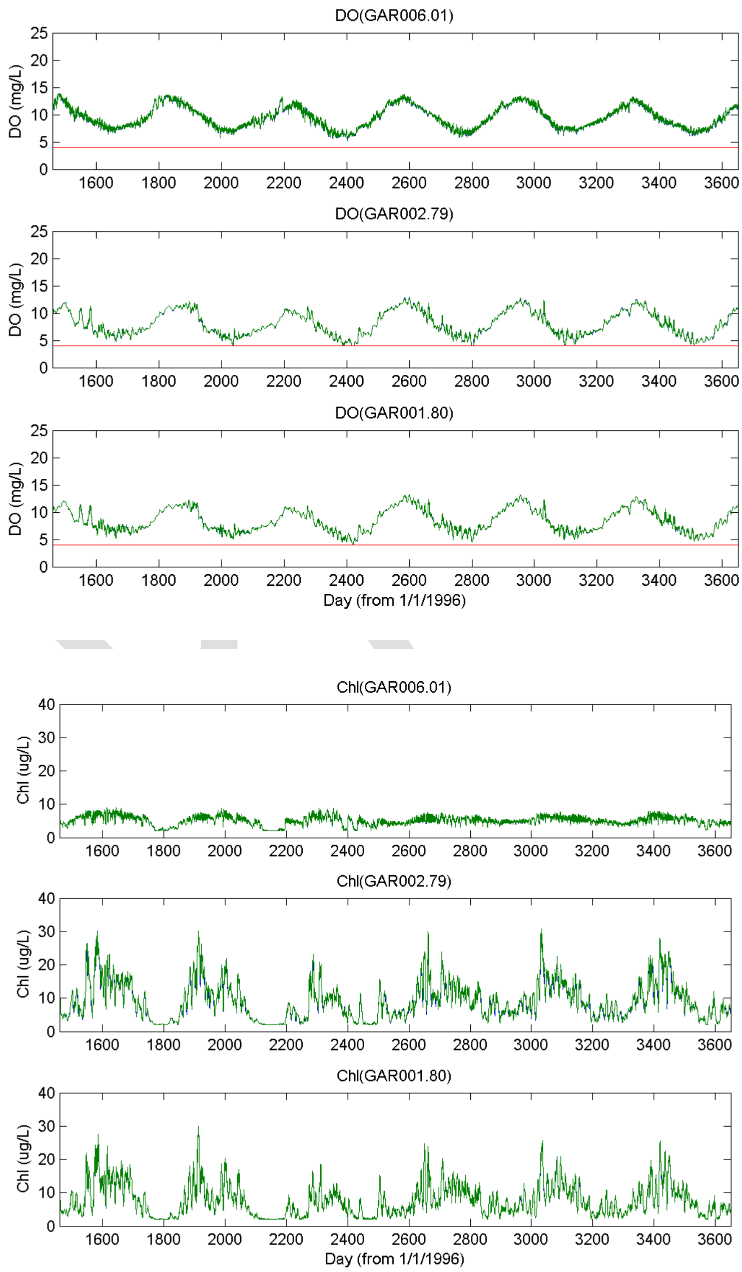


Figure A-16: DO and Algae Distribution after 34% Reduction of TN

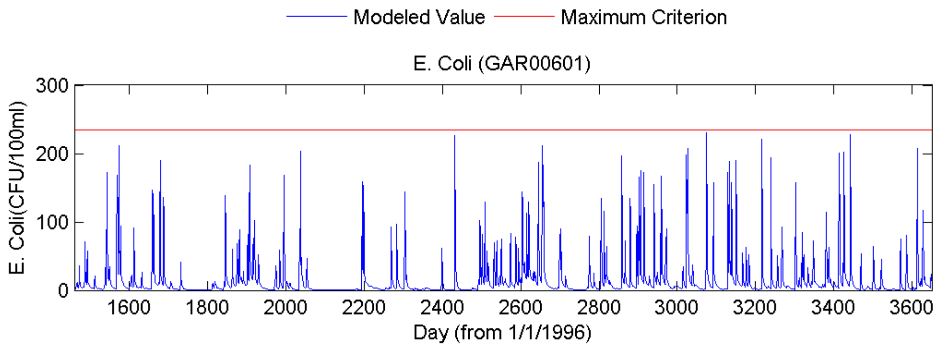


Figure A-17: Distribution Enterococci after 60% Reduction of Loadings in the Watershed

The loadings for each bacterial source were determined based on source assessment (Appendix B). Load allocations were determined by multiplying the total current and allowable loads by the representative percentage. The percent reduction needed to attain the water quality criterion was allocated to each source category. The results are presented in Table A-2.

The TMDL seeks to eliminate 100% of the human-derived fecal component regardless of the allowable load determined through the LA process. Human-derived fecal coliforms are a serious concern in the estuarine environment and discharge of human waste is precluded by state and federal law. According to the preceding analysis, reduction of the controllable loads from human, livestock, and pets, will not result in achievement of the water quality standard. Absent any other sources, the reduction is allocated to wildlife. The allocations presented demonstrate how the TMDLs could be implemented to achieve water quality standards; however, the state reserves the right to allocate differently, as long as consistency with the achievement of water quality standards is maintained.

Table A-2. Load Allocation and Required Reduction for Enterococci

Category	Source Allocation	Current Load (Counts/Day)	Load Allocation (Counts/Day)	Required Reduction
Livestock	58.98%	2.65E+10	2.30E+08	99.14
Wildlife	39.49%	1.78E+10	1.78E+10	0.00
Human	0.01%	4.50E+06	0	100.00
Pets	1.51%	6.80E+08	0	100.00
Total	100.00%	4.50E+10	1.80E+10	60.00

Appendix B: Calculation of Population Numbers

The process used to generate population numbers used for the nonpoint source contribution analysis for the four source categories: human, livestock, pets, and wildlife is described for each below.

B.1 Human

The number of people contributing fecal coliform from failing septic tanks were developed in two ways and then compared to determine a final value.

1) Deficiencies (septic failures) from the DSS shoreline surveys were counted for each watershed and multiplied by 3 (average number of people per household).

2) Numbers of households in each watershed were determined from US Census Bureau data. The numbers of households were multiplied by 3 (average number of people per household) to get the total number of people and then multiplied by a septic failure rate* to get number of people contributing fecal coliform from failing septic tanks.

*The septic failure rate was estimated by dividing the number of deficiencies in the watershed by the total households in the watershed. The average septic failure rate was 12% and this rate was used as the default unless the DSS data indicated that septic failure was higher.

B.2 Livestock

US Census Bureau data were used to calculate the livestock values. The numbers for each type of livestock (cattle, swine, sheep, chickens (big and small), and horses) were reported by the county. Each type of livestock was assigned to the landuse(s) it lives on, or contributes to by the application of manure, as follows:

Cattle	Cropland and Pastureland
Swine	Cropland
Sheep	Pastureland
Chickens	Cropland
Horses	Pastureland

Geographic Information System (GIS) was used to overlay data layers for several steps:

1) The county boundaries and the landuses to get the area of each landuse in each county. The number of animals was divided by the area of each landuse for the county to get an animal density for each county.

2) The subwatershed boundaries and the landuses to get the area of each landuse in each subwatershed.

3) The county boundaries and the subwatershed boundaries to get the area of each county in each subwatershed.

Using MS Access, for each type of livestock, the animal density by county was multiplied by the area of each landuse by county in each subwatershed to get the number of animals in each subwatershed. The number of animals in each subwatershed was summed to get the total number of animals in each watershed.

B.3 Pets

The dog population was calculated using a formula for estimating the number of pets from national percentages, reported by the American Veterinary Association:
dogs = # of households * 0.58. US Census Bureau data provided the number of households by county. The number of dogs per county was divided by the area of the county to get a dog density per county. GIS was used to overlay the subwatershed boundaries with the county boundaries to get the area of each county in a subwatershed. Using MS Access, the area of each county in the subwatershed was multiplied by the dog density per county to get the number of dogs per subwatershed. The number of dogs in each subwatershed was summed to get the total number of dogs in each watershed.

B.4 Wildlife

B.4.1 Deer

The numbers of deer were calculated using information supplied by DGIF, consisting of an average deer index by county and the formula:
#deer/mile^2 of deer habitat = (-0.64 + (7.74 * average deer index))
Deer habitat consists of forests, wetlands, and agricultural lands (crop and pasture).
GIS was used to overlay data layers for the following steps:

1) The county boundaries and the subwatershed boundaries to get the area of each county in each subwatershed.
2) The subwatershed boundaries and the deer habitat to get the area of deer habitat in each subwatershed.

Using MS Access, number of deer in each subwatershed was calculated by multiplying the #deer/mile^2 of deer habitat times the area of deer habitat. The number of deer in each subwatershed was summed to get the total number of deer in each watershed.

B.4.2 Ducks and Geese

The data for ducks and geese were divided into summer (April through September) and winter (October through March).

Summer

The summer numbers were obtained from the Breeding Bird Population Survey (US Fish and Wildlife Service) and consisted of bird densities (ducks and geese) for 3 regions: the southside of the James River, the rest of the tidal areas, and the salt marshes in both areas. The number of ducks and geese in the salt marshes were distributed into the other 2 regions based on the areal proportion of salt marshes in

them using the National Wetland Inventory data and GIS.
Winter

The winter numbers were obtained from the Mid-Winter Waterfowl Survey (USFWS) and consisted of population numbers for ducks and geese in several different areas in the tidal region of Virginia. MS Access was used to calculate the total number of ducks and geese in each area and then these numbers were grouped to match the 2 final regions (Southside and the rest of tidal Virginia) for the summer waterfowl populations.

Data from DGIF showed the spatial distribution of ducks and geese for 1993 and 1994. Using this information and GIS a 250m buffer on each side of the shoreline was generated and contained 80% of the birds. Wider buffers did not incorporate significantly more birds, since they were located too far inland. GIS was used to overlay the buffer and the watershed boundaries to calculate the area of buffer in each watershed. To distribute this information into each subwatershed, GIS was used to calculate the length of shoreline in each subwatershed and the total length of shoreline in the watershed.

Dividing the length of shoreline in each subwatershed by the total length of shoreline gives a ratio that was multiplied by the area of the watershed to get an estimate of the area of buffer in each subwatershed. MS Excel was used to multiply the area of buffer in each subwatershed times the total numbers of ducks and geese to get the numbers of ducks and geese in each subwatershed. These numbers were summed to get the total number of ducks and geese in each watershed. To get annual populations, the totals then were divided by 2, since they represent only 6 months of habitation (this reduction underestimates the total annual input from ducks and geese, but is the easiest conservative method to use since the model does not have a way to incorporate the seasonal differences).

B.4.3 Raccoons

Estimates for raccoon densities were supplied by DGIF for 3 habitats—wetlands (including freshwater and saltwater, forested and herbaceous), along streams, and upland forests. GIS was used to generate a 600ft buffer around the wetlands and streams, and then to overlay this buffer layer with the subwatershed boundaries to get the area of the buffer in each subwatershed. GIS was used to overlay the forest layer with the subwatershed boundaries to get the area of forest in each subwatershed. MS Access was used to multiply the raccoon densities for each habitat times the area of each habitat in each subwatershed to get the number of raccoons in each habitat in each subwatershed. The number of raccoons in each subwatershed was summed to get the total number of raccoons in each watershed.